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Ernest E. Thum, Editor

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Improved Silicon-Irons* for Electrical Equipment

By Weston Morrill
Head of Metallurgical Section
Pittsfield (Mass.) Works Laboratory
General Electric Co.

A brief summary of a 15-year study of means whereby large crystals can be made to grow in transformer sheet, at will, with axes pointed in a uniform direction.

WITHIN an organization having as diverse interests as General Electric Co.'s, it is obviously an advantage to establish a general research laboratory where new materials, processes and theories are initiated and studied; likewise to maintain works laboratories which put these general findings into the materials and equipment for sale. This indeed is the situation. The "Research Laboratory" has been in Schenectady since 1905; at present there are 24 "Works Laboratories" attached to the various manufacturing plants — three of them being established over 50 years ago.

The Works Laboratories have four primary functions: *(a)* They carry on an extensive program of applied research and development, supplemented where necessary and desirable by basic research as applied to local problems. *(b)* They serve as materials and process engineering consultants to factory and design groups, and it is in this capacity that they are responsible for adapting all pertinent research and materials developments to General Electric's needs. *(c)* They establish pilot plant operations so that the "bugs" may be worked out of new materials and processes before placing them in regularly scheduled production. *(d)* They develop and control plant processes, establish specifications for purchased materials and police their specifications by tests upon raw materials.

Operations of such a complete laboratory system may well be illustrated by the work that has been underway since 1903 on silicon-iron* alloys. Following their discovery in England about 60 years ago, commercial interest was not very great until the development of alternating current machinery, at about the turn of the century. In motors and transformers this material is used as thin sheets. It is lacking in ductility so it was first necessary to learn how to roll it. Next, its magnetic properties depend on *(a)* its chemical composition (so it was necessary to purify it) and *(b)* its crystalline orientation (so it was necessary to grow large crystals in the sheet, each crystal, if possible, with its cubic edge pointed in a given direction). These operations involved specialized heat treatments, so this phase of the manufacturing process has received intensive study.

All these aspects of the problem have been influenced by metallurgists working with General Electric Co. In 1903 the first commercial heat of silicon-iron to be made in America was melted at the River Works of G. E. Co. in Lynn, Mass., and shipped to Allegheny Steel Co.'s plant in Brackenridge, Pa., for rolling into sheet.† Wm. E. Ruder, the present head of the metallurgical division of the central Research Laboratory, turned his attention to the material shortly after he

*In shop parlance these are "electrical steels", although metallurgically they are "irons" in view of their low carbon content and their metallography — ferrite crystals (body-centered cubic) without transformations during heating or cooling.

†In Dr. Rettaliata's excellent review of "Low-Alloy Steels in the Electrical Industry" in *Metal Progress* last month, he states on p. 478 that "in 1906 a ton of 3.25% low-carbon silicon-iron, the first large commercial heat, was produced in England". This error in ascribing priority is only to be expected in a branch of industry wherein so much secrecy still exists as in the manufacture of electrical sheets.

joined the youthful organization in 1907, and discovered the fact that magnetic measurements on a large iron-silicon crystal depended on the direction of the magnetizing force — that is, the way the cubic crystal lined up in the test equipment.* The crystal, in scientific terms, is anisotropic. The outstanding contribution of General Electric's laboratories to the present-day magnetic properties of silicon-iron sheet is the practical development and utilization of this anisotropic property of metals.

In the body-centered cubic lattice structure of ferrous alloys the great magnetic superiority of the cube edge direction is illustrated by magnetization curves typical of each of the three principal axes as measured on a single crystal of iron. While, as remarked above, this magnetic phenomenon of single crystals was discovered in our Research Laboratory many years ago, its practical utilization awaited a means whereby preferred crystal growth could be induced, in commercial practice, in multicrystalline materials. Such a system was discovered by Smith in England and Goss in this country, who demonstrated in 1933 that, by a series of critical cold reductions and heat treatments, secondary grain growth of a preferred type could be induced in 3% silicon-iron. Their process resulted in some 25% of the crystals having a cube edge parallel to the direction of rolling. The magnetic properties in that direction were quite phenomenal.

Fig. 1 — Controlled Crystallization

It was at this very typical point that the problem was handed to the Pittsfield Works Laboratory. We were asked to study methods of increasing the *degree* of preferred crystal orientation to 100% and to alter, if possible, the *type* of preferred orientation. The first problem has been solved very satisfactorily; cooperative effort between our chemists, physicists and metallurgists has brought 95% of the crystals into alignment. The second problem — change of *type* of orientation — is still under investigation through basic research on the mechanisms of crystal nucleation and growth.

Since it was evident from the work of Smith and Goss that a preferred strain introduced by controlled cold rolling was not completely effective in guiding the growth of a majority of crystals to the desired orientation, some secondary opposing force must exist. It was recognized that *any* existing differential, be it that of strains, chemical impurities, or temperatures, may prevent a satisfactory result, or induce an unsatisfactory crystal growth. Temperature differentials are easily controlled, and so could be eliminated as a factor. However, dissolved or atomically dispersed chemical impurities, situated interstitially in the iron crystal lattice, might set up striated chemical strain. From the point of view of an embryo crystal just starting to grow, such strains would be indistinguishable from the preferred rolling strain. It was reasonable to assume, therefore, that the poorly oriented crystals in the products of Smith and Goss were misled at an early age by chemical strains.

A reasonable move, based upon this deduction, was the preparation of pure iron-silicon alloys by vacuum melting techniques. Such materials, produced from hydrogen-fired electrolytic iron and 99.9% silicon, had a total impurity level well under 0.1%. Unfortunately, when processed and heat treated by standard procedures, the final purified product was characterized by very uneven crystal growth and by very little improvement in the degree of preferred crystal orientation over that of the impure commercial materials! Here indeed was a first-class dilemma; one could not live with chemical impurities, nor yet without them!

The mechanisms involved here are not well understood, even as yet, but certain deductions were possible. It had been fairly simple to establish that — at a given temperature level and under

*See Fig. 9 on page 709 for an illustration of how this is done.

most circumstances — well oriented crystals tended to nucleate somewhat faster than poorly oriented crystals. In other words, the energy differential before and after growth of well oriented crystals is greater than for poorly oriented crystals. This gave rise to the thought that certain impurities normally present in the commercial alloy act as energy barriers to the growth of poorly oriented crystals. Such barriers might retard the growth of poorly oriented crystals for periods long enough to allow the more powerful, well oriented crystals to complete their growth. In chemically pure alloy the absence of these energy barriers must have allowed the promiscuous growth of crystals of many orientations, although the preferred orientation predominated, due to its faster nucleating rate and higher energy differential.

Of course, in the chemically pure material the absence of any misguiding chemical strain must be regarded as a favorable factor. The ideal commercial sheet, therefore, should have a complete absence of any impurities except those which act as deterrents to the growth of poorly oriented crystals. To isolate for individual study any one of the myriad of elements and compounds present in commercial metal, from merest traces to amounts of 0.2%, is obviously an impossible job, but I should like to illustrate for you the effects of one.

The retarding effect of nitrogen on crystal growth is most interesting. The normal nitrogen content of silicon-iron is of the order of 0.0005%. As this amount is gradually increased to 0.0010%, the number of secondary crystals which will grow at the expense of the recrystallized matrix becomes fewer, their size becomes larger and their orientation more perfect. At some critical content near 0.0015% the growth-inhibiting effect becomes powerful enough to prevent the growth of any crystals, even the most perfectly oriented. (It should be remembered that silicon contracts the gamma-iron field in the equilibrium diagram, so that a 3% silicon alloy possesses no allotropic modifications to cause large crystals, formed during high-temperature annealing, to recrystallize on cooling.)

This effect of nitrogen has been strikingly illustrated in Fig. 1. Using a piece from a regular commercial lot of silicon-iron as cold rolled, all of the area outside the G. E. monogram has been artificially nitrided, while the area of the letters and the circle were protected from nitrogen. In the subsequent heat treatment large, well-oriented crystals grew to fill the monogram, while no crystal growth developed in the background. When a phenomenon can be induced or inhibited at will, it may be said to be reasonably under control.

In addition to the vast amount of laboratory work in physical metallurgy and chemistry necessary to bring this type of oriented crystal growth under control, the metallurgists of the Pittsfield Works Laboratory, in cooperation with those of Allegheny Ludlum Steel Corp., operated a 50-ton openhearth furnace on an experimental basis for one year. The result has been the production of thousands of tons of silicon-iron strip having the best magnetic quality and lowest quality spread of any magnetic material ever produced in commercial lots.

Before I leave this subject, I think the reader might be interested in the economic advantage of this high-quality silicon-iron alloy. Figure 3 shows the progress through the years in reducing the energy losses in magnetic material for transformer cores. The pictures show the effect on total weight and size of a 1.5-kva. transformer as its core is improved in quality. In the period of 10 years a saving of 50% in steel, copper, insulation and oil has been effected by the introduction of cores having superior magnetic properties due to the development of a high degree of preferred crystal orientation.

In the commercial production of these alloys, accurate heat treatment is a prime essential. Not only can certain undesirable impurities be removed by proper annealing (as, for example,

Fig. 2 — The Author in Magnetic Laboratory, Pittsfield Works

in purified hydrogen) but desirable impurities introduced (as, for example, nitrogen). Even the matter of stress relief around the edges of punched laminations must be done with discretion, else the surface will acquire undesirable characteristics.

An example of the latter may be cited in studies undertaken at the Fort Wayne Works Laboratory to determine equilibrium constants of furnace atmospheres — an excellent example of the application of physical chemical theory to practical metallurgical problems.

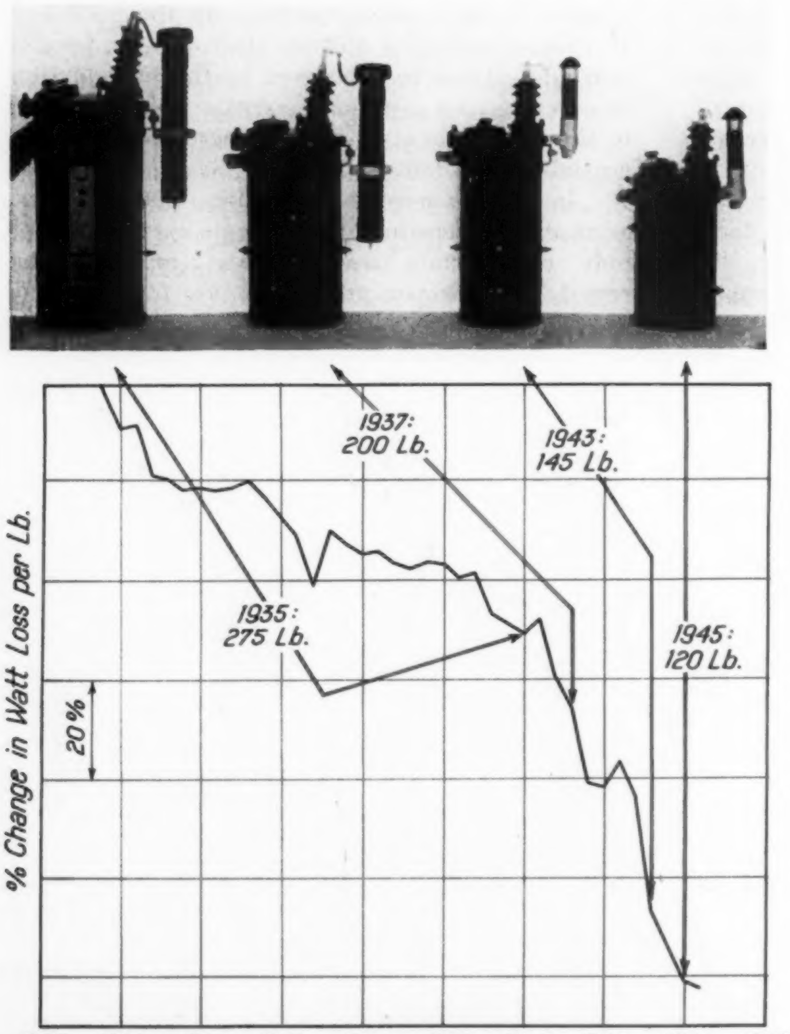
In the manufacture of fractional horsepower motors, as in most inductive apparatus, the controlling design factors are the magnetic properties of the core materials. These magnetic materials must be cheaply yet effectively heat treated to relieve strain and eliminate chemical impurities, mostly carbon, and at the same time develop a satisfactory insulating oxide scale. It is the solution of this heat treating problem to which the Fort Wayne metallurgists have applied themselves.

One of the obstacles of such an investigation is the accurate analysis of the furnace atmosphere at operating temperatures. This was accomplished with some accuracy by making the analysis of the incoming gas for hydrogen, carbon monoxide and dioxide and water vapor, then using chemical equilibrium constants of the water-gas reaction to compute the amount of water vapor that would be formed at the elevated temperature. In this way the equilibrium composition under operating conditions could be calculated from the incoming gas analysis. However, since reactions between gas and steel will upset this theoretical composition, it has been necessary to design apparatus wherein hot furnace gases may be sampled and cooled quickly enough to maintain high temperature compositions for Orsat analyses.

Using this approach, equilibrium constants for the specific oxidizing, reducing, carburizing and decarburizing components could be determined for various heat treating temperatures. Applied to silicon-iron samples under actual annealing conditions, it has been established experimentally that the calculated relationships are accurate in determining the tendencies of the atmosphere to react with the metal. This work has led to the establishment of a quality control system for annealing electrical sheet in a controlled atmosphere, so that a uniform core material with oxide film insulation and controlled carbide phase may be consistently produced. This method of attack may now be used to develop improved magnetic properties by suitable study of atmosphere reactions during the heat treating cycle.

These problems in improving silicon-irons for electrical equipment are illustrative of many of the contributions of the metallurgist to the electrical industry. Within the unique laboratory structure of General Electric such research and development projects receive a maximum of encouragement and projection to a successful conclusion.

Fig. 3 — Quality Development of Transformer Grade Silicon-Iron From 1909 to Date, and Its Influence on Size and Weight of 1.5-Kva., 7200-Volt Transformers Since 1935



Specialized Foundry Control for Composite Castings

By Arthur K. Higgins
Superintendent of Chemistry & Metallurgy
Allis-Chalmers Mfg. Co.
Milwaukee, Wis.

A normal proportion of foundry losses becomes unendurable when making composite castings, such as the fixing of forged turbine blades into cast wheel segments, because of the high money value of the inserts. Nevertheless, the problems of forming a good alloy bond between cold insert and molten metal are susceptible of metallurgical analysis. When the elements are understood and properly controlled, foundry losses can be reduced to 0.2% over long periods of time.

AT SOME TIME in its history, every progressive foundry is faced with a type of casting, outside of normal foundry technique, but so attractive for any of a number of reasons that development of unusual production methods seems reasonable. A not uncommon item of this type is a casting having prefabricated inserts included in its structure, either for strengthening vital portions, or for giving specialized properties to limited surface areas. It is true that the foundry is daily faced with a similar problem in its normal use of chaplets and internal chills—and, although these ordinary requirements are seldom severe, the scrap losses due to failure of the chaplets to bond may be disturbingly high.

Examples of the foregoing techniques have been developed by some foundries for "casting in" cooling or heating coils into process equipment parts, for surrounding soft hubs with more wear resistant disks, for providing better wearing surfaces on brake drums, for bonding of bearing materials to shells of higher strength, and for placing vanes and buckets of high alloy in wheels or rings of ordinary steels. In almost all of these applications we find that careful preparation and precise control are essential if the operation is to be economically sound.

Among problems of this type, few receive more critical inspection than the one of casting an alloy base around a group of prefabricated inserts that must bear tensile and fatigue loads. Requirements of this type of casting are extremely severe, since the junction between insert and base must be strong enough to equal the tensile strength of the insert itself, while at the same time the insert must not be adversely affected by the manufacturing process. A few small gas holes along the junction between insert and casting may be tolerated, but in no case may a part of the insert be melted or washed away. The necessary strong bonds between insert and casting will result only if the major portion of the insert's surface is thoroughly fused and alloyed with the base or surrounding metal.

In the study of a problem of this type, the metallurgist will first deduce the requirements for the materials used. He will not consider the obvious need for adequate strength and resistance to corrosion, under conditions of normal operation, since these needs are met by ordinary judgment of the engineers responsible for the design. The special requirements of metallurgical properties must, however, be considered in detail.

First, of course, the metal being cast must have a suitable melting point. It must not have a higher melting point than the insert used, for obvious reasons. It may have about the same melting point as the insert if the latter is of large cross section, but it is preferable that it be substantially lower than the melting point of the insert.

Secondly, the material being cast must not form tenacious surface films since such films tend to fold around the surfaces with which they come in contact, and prevent bonding. Typical examples of this type of film-forming alloys are those containing aluminum (such as the aluminum and manganese bronzes) and copper-base alloys that contain chromium. When either aluminum or chromium is present in the molten alloy, even in small amounts, the resulting bond with solid metallic inserts must be viewed with suspicion.

A third requirement of equal importance in highly stressed castings is that the cast metal must retain, as a residual, some gas-absorbing constituent, since some gases are inevitably adsorbed and combined on the surface of the insert. Phosphorus and silicon are fairly effective in this respect, while magnesium and calcium — with their high affinities for most of the common gases — are particularly good.

The fourth requirement is that the casting metal must not form brittle intermetallic compounds with the material of which the insert is made. If it does, mechanical failure of the bond will occur when the insert reaches its elastic limit, or has elongated enough to exceed the shear strength of any portion of the bond. As soon as shear has begun, it will continue until complete failure results.

Undesirable combinations of insert and casting might be such pairs as tin-base or zinc-base alloys cast against copper-base inserts, high-phosphorus alloys against any of the steels, or high-aluminum alloys against copper alloy insert. Fortunately, the only one of these combinations that is likely to be considered is that of high-phosphorus alloys against steel. Good combinations are represented by the copper-base alloys with copper-nickel inserts, and some of the copper-nickel alloys with almost any of the steels.

Where a satisfactory choice of metal pairs has been made and when optimum technique is used, a true alloying action can be expected, in the sense that the grain structure of the insert will determine the orientation of the surface layers of cast metal, and grain boundaries will continue across the casting-insert interface. Examples of satisfactory and unsatisfactory bonds are shown in the micrographs of Fig. 1 and 2.

The material of which the insert is to be made is primarily dictated by design considerations and by the corrosion resistance required — and, in turn, serves to influence the choice of base material. Having selected the materials for insert and for casting, the next step is the preparation of the inserts for the casting operation.

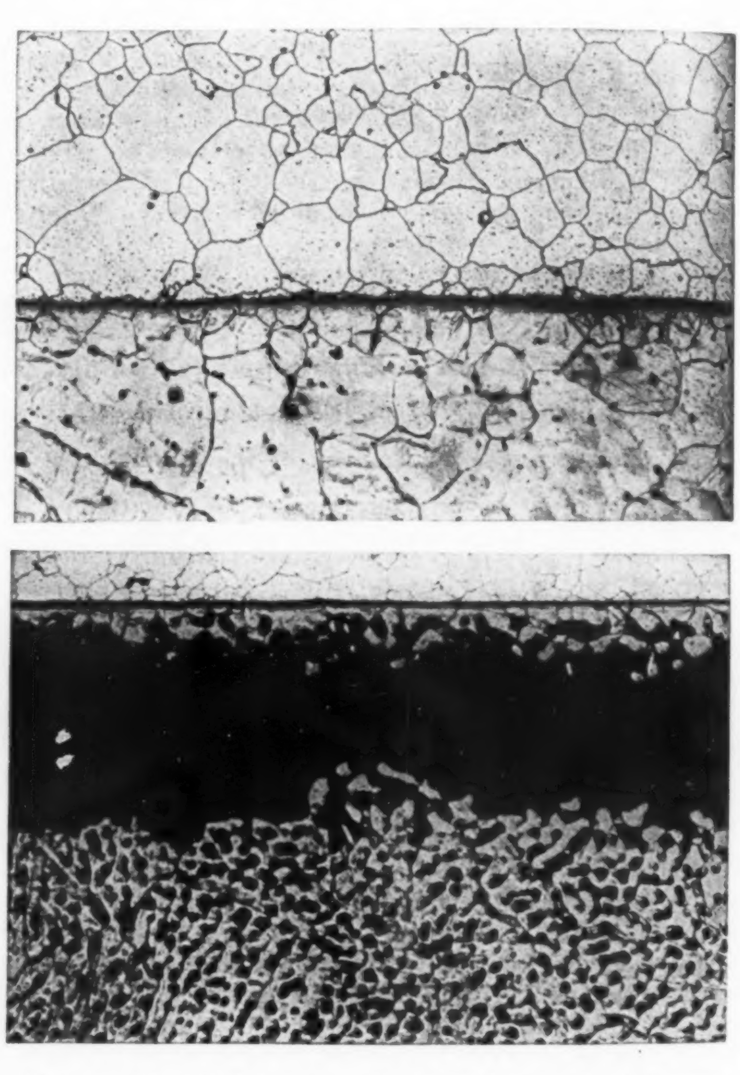


Fig. 1 and 2 — Satisfactory and Unsatisfactory Bond Between Insert (Above) and Casting (Below). 100×. Note numerous small gas holes in casting, in addition to wide gap at interface

Surface Preparation of Inserts

The normal requirements are that the surfaces must be free from dirt, rust, or scale, and must not have heavy oxide or other chemical films that may react with the base material being cast around them. Actually, the attainment of these conditions is not easy. If the insert is a common steel, it will be somewhat scaled (if heat treated),

and at the very least will have its surface contaminated with oil, dirt and finger marks from handling and manufacturing operations. After a degreasing operation, steel surfaces should be carefully inspected for scale, particularly the rolled-in scale that may result from skin working passes on rolled bars or sheets that were not adequately pickled after the previous anneal. Usually a special etching technique must be developed to detect defects of this type. All pieces having rolled-in scale should be discarded.

Following such inspection, the insert must be *vigorously* cleaned. Suitable methods are by electrolytic etching with the work as anode, by vapor blasting, or by any other similar process.

If the material is resistant to rusting and atmospheric oxidation, it may be cast-in without further treatment.

When it becomes necessary to protect the insert from rusting or oxidation, it is most satisfactory to plate the carefully cleaned surface with a noble metal. Silver has been used satisfactorily by us. Other materials might well be suitable, such as tin and nickel, but care must be taken to avoid metals such as chromium (which, because of its high modulus of elasticity, reduces the fatigue life of the insert). The volatile metals, zinc and cadmium, seem unsuitable because of their tendency to form gas holes during casting.

For some applications — notably when casting steel inserts into gray iron — thin phosphate coatings seem suitable for the steel inserts. Other chemical protections, such as dipping in sodium chromate solutions, are not satisfactory, because the coatings break down at casting temperatures and liberate excessive amounts of gas.

Molding Practice

Proper foundry procedures for making castings of this type are the most difficult to set up. Scrap must be kept at a minimum, because the value of the group of inserts included in a single casting may far exceed the cost of the cast metal and the making of the mold. It therefore becomes economical to apply foundry control that goes beyond normal practice.

Since the sizes of composite castings may vary from a few ounces to several hundred pounds, no single mold design is suitable for all. We can, however, lay out certain principles of operation that are common to all.

Because the surfaces of the inserts must be scrupulously clean, we may not use baked cores around the inserts, since they deposit films of varnish and oven smut on the inserts — unless the units are so large that the inserts may be cleaned by hand after the cores are baked. All the smaller assemblies, which make up the greatest bulk of the work, must be rammed up in green sand cores using clay binders rather than organics. Since the area of the core between the inserts is usually small, the green sand cores should be allowed to air-dry to some extent, so that less steam will be formed when molten metal enters. If a very wet sand is used, heat from the casting face added to the heat carried back along the inserts will generate steam at a greater rate than can be accommodated by the sand's porosities, and "core blows" will result. The mold itself may be made of either green or dry sand, since it is made before the core carrying the inserts is put in place. Such necessary conditions are sketched in Fig. 3.

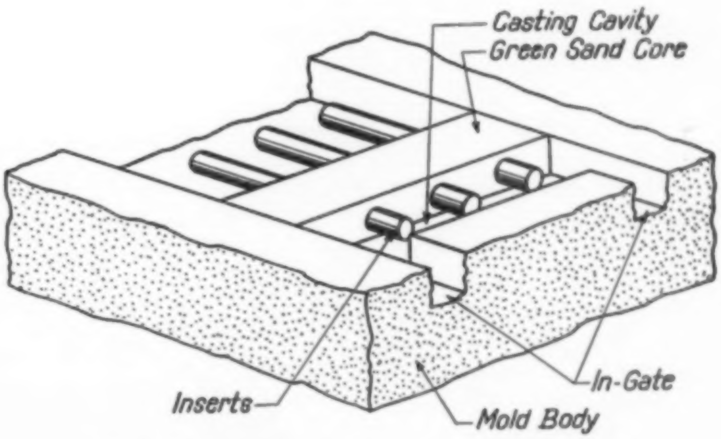


Fig. 3 — Diagrammatic Sketch of Proper Method of Molding for a Casting With Metal Inserts

Gating the Mold

Gating of the mold is extremely critical. Experience has shown us that certain conditions apply:

First, large amounts of metal must not flow past any insert, since — regardless of the temperature, as long as it is above the melting point of the cast metal — the liquid metal exerts a solvent action on the insert in much the same fashion as a cake of salt is eventually dissolved in the warm saliva of a cow's tongue.

Second, the cast metal must reach the surface of the insert with enough residual heat to remelt the chilled layer that forms at first contact with the cold surface. If this condition does not obtain, inevitable traces of gas adsorbed or formed on the surface of the insert cannot be absorbed by

the still liquid metal, and bubbles will be formed along the surface of the insert, destroying the bond between it and the cast metal.

If we are to insure these two conditions, the metal must enter the mold cavity at a point very near to its final position. This is not an easy condition to attain; however, two general considerations apply: *(a)* If the casting is short, it may be gated from both ends, with the gates so oriented that the entering metal does not impinge on any of the inserts. *(b)* If the casting is long or contains a large volume of metal, a fin gate of the type commonly used on test bars may be effective. It, too, should be placed to avoid directing the entering stream against any insert.

With the above gating principles in mind, it is possible to design a mold that will yield satisfactory results. Elimination of unsoundness due to shrinkage, and other casting difficulties are not peculiar to the problem at hand.

Melting Requirements

The preparation of the melt for casting follows usual foundry practice except that extreme care must be used to secure uniformity. Cleaned return-gates, as well as new metal used in the charge, should be weighed to allow precise control of deoxidation, since the success of the process depends to a large extent on the retention of trace amounts of the active deoxidizer in the melt at the time of pouring.

If the melting is done under an open flame, control of furnace atmosphere must be good and, where possible, proportioning-type burner equipment with frequent analysis of the combustion products seems best — although excellent results have been obtained with less precise equipment.

Time of addition of the deoxidizing material should also be controlled within narrow limits, preferably by clock, since losses vary as a function at the time.

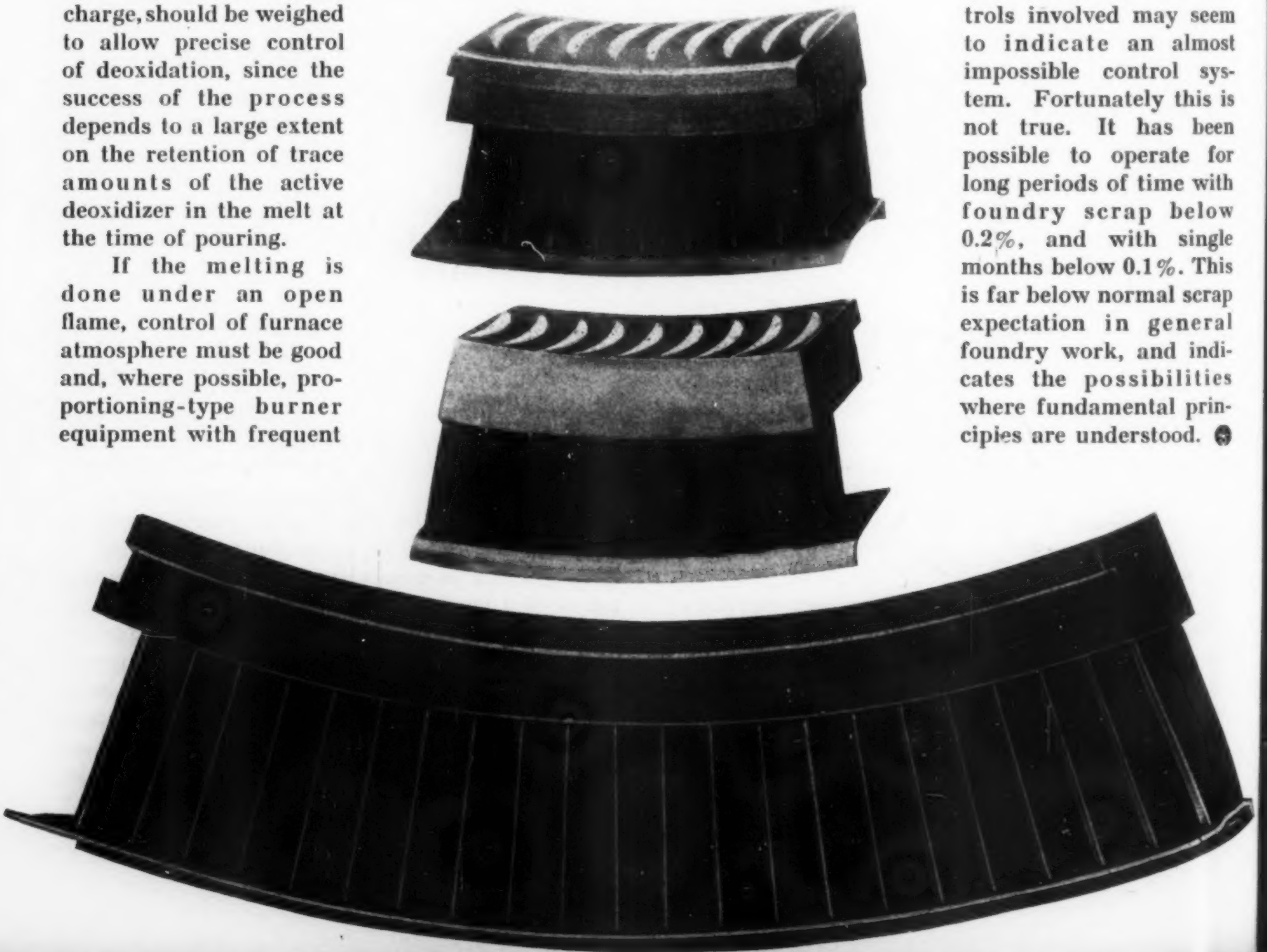
The final variable, pouring temperature, can nullify all of the preceding cautions if it is not properly controlled. Too high a pouring temperature will obviously melt the inserts. Too low a temperature will result in lack of bond, entrapped gas, and cold-shuts between the inserts.

Proper temperatures will normally fall within a 50 to 70° F. range. Since the desirable temperature depends on the gate as well as the metal, consistent gating practice is imperative.

The usual practice is to bring the pouring ladle to the floor with an excess temperature of 50 to 100° F. The temperature is carefully followed with a pyrometer suited to the material, until the upper pouring limit is reached. Pouring is then started at once and continues until the pyrometer indicates that the lower pouring limit is reached. After this has been reached, no more castings are poured, even if half the metal remains in the ladle.

This description of the variables and controls involved may seem to indicate an almost impossible control system. Fortunately this is not true. It has been possible to operate for long periods of time with foundry scrap below 0.2%, and with single months below 0.1%. This is far below normal scrap expectation in general foundry work, and indicates the possibilities where fundamental principles are understood.

Fig. 4 — Examples of Monel Turbine Blades With Cast Bronze Root Section



Fatigue Limit of S.A.E. 1095

After Various Heat Treatments

By Arthur C. Forsyth
Assistant Professor of Metallurgical Engineering
University of Illinois
Urbana

and Roland P. Carreker
Physical Metallurgy Group, Research Laboratory
General Electric Co.
Schenectady

The fatigue limit of S.A.E. 1095 was determined for three conditions of heat treatment that resulted in a hardness of Rockwell C-53: Water quenched and tempered, austempered, and martempered and tempered. The fatigue limit for martempered specimens, 160,000 psi., was considerably higher than for the others, namely, 124,000 and 130,000 psi. S-N diagrams and tension-impact data are presented.

ENGINEERS are constantly demanding better service from metals in modern machinery. Higher operating speeds necessitate smaller masses in moving parts and these smaller masses usually result in higher stress. Higher operating speed means a greater frequency of stress reversal. Higher stress and more frequent reversal of stress too often cause fatigue failure. The engineer cannot accurately calculate the fatigue strength of steel. Therefore he must design on the basis of experimentally determined fatigue limits.

Fatigue failure, fatigue limit and S-N curves are familiar terms to engineers and metallurgists. It is not the intention here to discuss or define these terms, but rather to show that the fatigue limit of a given steel may be increased by metallurgical means that do not depend on increased hardness. Experimental S-N curves are presented and an explanation based on microstructure is offered.*

Consider a plain hypereutectoid steel, S.A.E. 1095. As rolled, as cast, or as annealed, this steel has a relatively low fatigue limit: 30,000 to 50,000 psi. The strength can be greatly increased by quenching the steel in water but such quenched steel is almost hopelessly brittle. A compromise between high strength and high ductility is usually obtained by tempering. Water (or oil) quenching followed by tempering is the standard procedure when high strength is desired. But other treatments, involving interrupted quench, may be used.

By proper choice of temperature and time, a given steel may be heat treated to the same hardness level in three ways: by water quenching and then tempering, by austempering, or by martempering and then tempering. At the same hardness, the tensile strengths are approximately equal. However, the resistance to fatigue failure *may* be influenced by the method of heat treatment. The experiments described here were made in order to determine the existence and magnitude of this effect, eliminating all variables except the method of heat treatment. Each specimen was checked to insure constant hardness and constant austenitic grain size.

Specimen Size — S.A.E. 1095 steel was obtained in the form of ⅝-in. round, cold drawn drill rod with a spheroidized microstructure. Fatigue and tension-impact specimens were machined to the dimensions shown in Fig. 1 and 2. Fatigue speci-

*Mr. Carreker conducted the tests for his thesis in partial fulfillment of requirements for the Master of Science degree at the University of Illinois.

mens were polished in successive stages through 000 paper, with the final polish longitudinal.

Heat Treatment — Specimens were packed in carburizing compound, previously established as inert with respect to this high-carbon steel. All specimens were austenitized for 1 hr. at 1500° F.

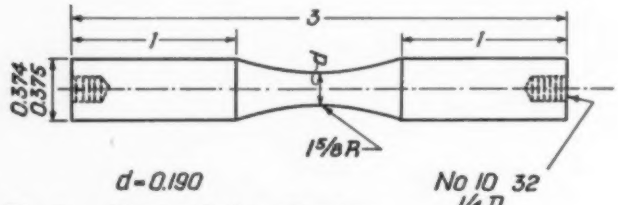


Fig. 1 — Krouse Fatigue Specimen

before being quenched. This treatment produced a uniformly fine austenitic grain size (A.S.T.M. 7 to 8). For austempering, the austenitized specimens were quenched into a lead-bismuth bath at 550° F., held for 1 hr., and then cooled in oil. For martempering, the austenitized specimens were quenched into a lead-bismuth bath at 450° F., held for 75 sec., and then cooled in air. (Compare these points on the TTT-diagram of Fig. 3.)

Both martempered and water-quenched specimens were tempered for 1 hr. at 550° F. and then cooled in oil. Each of these heat treatments produced the same hardness, approximately Rockwell C-53, which corresponds to a tensile strength of about 270,000 psi.

Test Procedure — Fatigue specimens were tested at 7000 r.p.m. in a Krouse high-speed repeated-stress machine, which employs the rotating cantilever-beam principle. Tension-impact tests were made on a Riehle combination impact testing machine, using the 200 ft-lb. capacity and

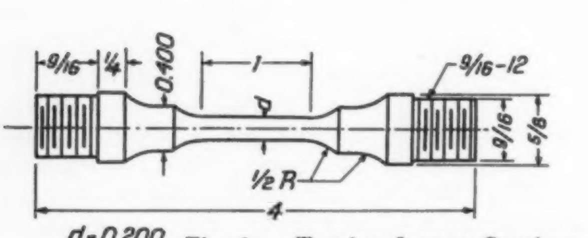


Fig. 2 — Tension-Impact Specimen

a striking velocity of 18.1 ft. per sec. All specimens were examined metallographically and by hardness tests to insure uniformity.

Fatigue Limit — Figure 4 indicates that the resistance to fatigue failure of specimens heat treated to the same hardness depends markedly on the heat treatment used to obtain that hardness. Conventional water quenching and tempering gave the lowest fatigue limit, 124,000 psi. The austempered specimens had a somewhat higher fatigue limit of 130,000 psi. By far the highest fatigue limit, 160,000 psi., was obtained with martempered and tempered specimens.

Tension-Impact — In Table I are listed the results obtained from unnotched tension-impact specimens heat treated by each of the methods described. Austempered specimens were toughest; quenched and tempered specimens were poorest.

Microstructure

The variation in endurance limit is caused by the difference in microstructure produced by the

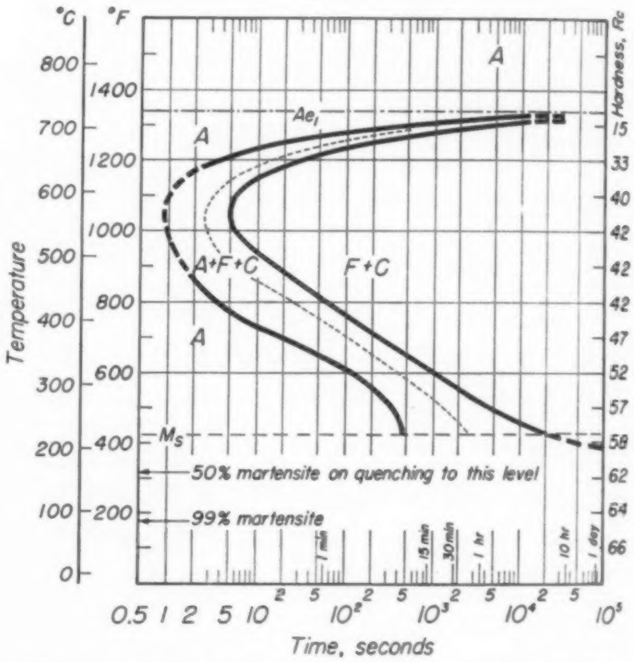


Fig. 3 — TTT-Diagram for 1095 (U.S. Steel Corp.)

three heat treatments. Davenport, Roff and Bain (*Transactions*, V. 22, 1934, p. 289) have reported that microcracks exist in such steels after quenching in water or oil. These microcracks are said to be caused by the very high thermal and transformational stresses that arise during quenching and the formation of martensite. The occurrence of microcracks and gross quenching cracks are direct evidence of the existence of regions of high stress within the metal. Low tempering temperatures, necessarily used when high hardness is desired, do not completely remove these microcracks or the stress concentrations. Either a small crack or a small region of high stress is an ideal spot for the fatigue fracture to begin.

Davenport and co-workers pointed out that the austempering process reduced both thermal

and transformational stresses. Microcracks do not occur with such treatments. They reported also that austempered steels were superior in impact and fatigue tests to quenched and tempered steels of comparable hardness.

Residual Stresses

With the development of martempering, it became possible to produce a martensitic structure without inducing the extremely high stresses that usually accompany this transformation. The specimen temperature is essentially uniform throughout, so that transformation occurs randomly throughout the specimen, instead of preferentially at the periphery. Thus the volume change accompanying the transformation is distributed uniformly throughout the specimen. The last portion to transform is not rigidly confined by the hard shell of prior transformation, as in conventional quenching. The temperature drops so slowly that only a small portion transforms per unit time. These factors reduce to a minimum the stresses accompanying the martensite transformation, and it is possible to produce a martensitic structure free from microcracks and regions of high stress concentration.

It is evident, from the consideration of microcracks and residual stresses, that both austempered and martempered specimens should have higher fatigue limits than water-quenched specimens of the same hardness. Our experiments confirm this expectation and also show that the martempered specimens are considerably better than the austempered specimens. Localized deformation by slip precedes fatigue failure. The yield strength of bainitic structures (formed by austempering) has been shown to be less than that of tempered martensitic structures of the same hardness.* Because of this difference in yield strength, the austempered specimens deform locally at a lower stress value than do the martempered specimens. Thus the austempered steel has a lower fatigue limit than the martempered specimens.

*"The Industrial Applications of Austempering", by E. E. Legge. *Metals and Alloys*, V. 10, 1939, p. 228.

Summary

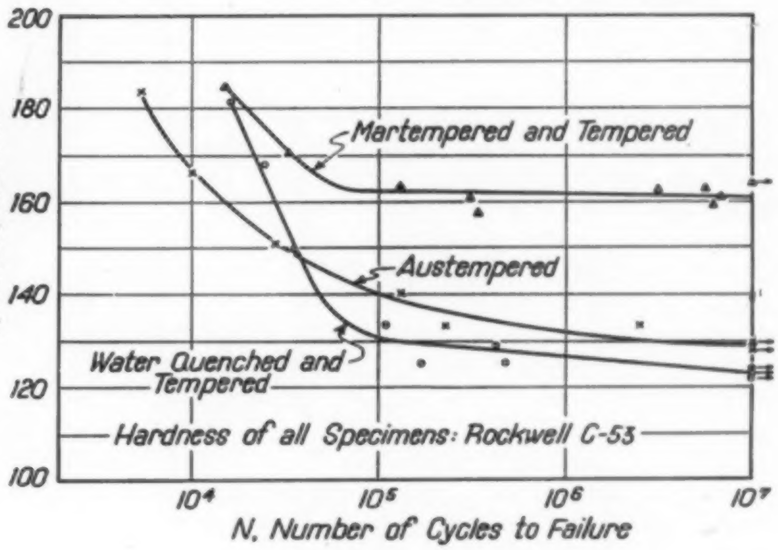
It should be emphasized that the numerical values for the fatigue limits reported here apply only to the test conditions described. The steel selected, S.A.E. 1095, is rather sensitive to quench cracking. A water quench was used. The extent of improvement by hot quenching would be expected to decrease as the hardness level decreases. These results were obtained using specimens designed to avoid stress concentrations. Practical designs rarely can employ such ideal conditions. Absence of residual stresses during transformation then becomes even more beneficial.

These experiments indicate that the more expensive martempering heat treatment may actually prove economically advantageous when the fatigue failure of steel parts with high hardness is a problem.

Table I — Tension-Impact Test Results

Specimen	Heat Treatment	Rockwell C Hardness	Ft-Lb.	% Elongation in 1 In.
1	Water Quench and Temper	53.0	12	0
2	Water Quench and Temper	52.5	14	0
3	Martemper and Temper	53.0	28	0
4	Martemper and Temper	52.8	24	0
5	Austemper	52.0	45	11
6	Austemper	52.5	40	8

Fig. 4 — S-N Diagrams for S.A.E. 1095 Treated in Three Ways: Water Quenched and Tempered, Austempered, and Martempered and Tempered. Each point represents one test



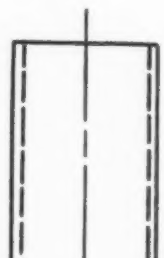
Bits and Pieces

Any book you may choose from the A.S.M. publications (except Handbook) for an acceptable item for these pages.

Drilling Very Hard Materials

If a small hole must be made in a very hard alloy such as Duriron, Stellite, or some of the new alloys for gas turbines, a method used for glass lens blanks will give good results. The scheme is by no means new, but probably not widely known among metallurgists.

The necessary equipment consists of a drill press, some diamond powder, and a short piece of copper tubing of proper diameter. The tube is slotted with a hacksaw, as shown in the accompanying sketch. The number of slots should be at least three, and may be more, depending on the size of the hole desired. It is important to taper the bottom of each segment.



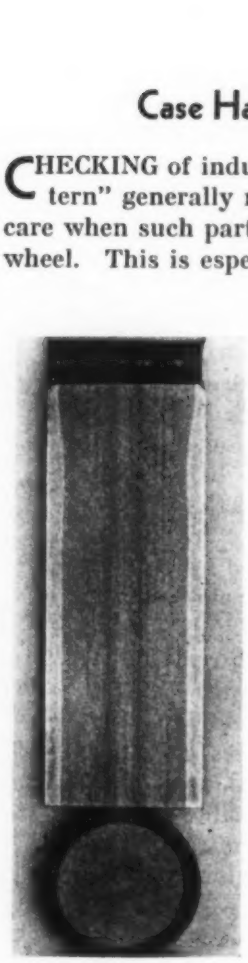
This copper tube then becomes a trepanning drill. A little diamond powder, mixed with olive oil, is smeared on the place where the hole is to be drilled. The particles of diamond become embedded in the soft copper and cut the hard surface of the metal being drilled; the teeth on the copper tube are only slightly worn. The drill press handle should be weighted so that steady pressure is applied. Direction of rotation is opposite what would be proper if the teeth were harder than the work — that is, the copper teeth drag rather than gouge. In this way, diamond or carborundum dust in suspension is drawn into the wedge-shaped clearance between tooth-rake and work.

If diamond powder is not available, carborundum and water can be used. This takes longer unless a steady stream of the fluid can be directed on the work.

This method has been used for cutting small holes in a Duriron corrosion specimen and gave excellent results. It took a long time, but it drilled a very fine, smooth hole. (David A. Vermilyea)

Case Hardness "Pattern"

Checking of induction hardened parts for "pattern" generally requires considerable time and care when such parts are being cut with a friction wheel. This is especially true where odd sections or considerable lengths are involved, or where new jobs or setups must be checked.



We have found that tempering at 950° F. enables us to saw the part readily. A light grind or polish smoothes the surface for etching. An ammonium persulphate etch brings out the originally hardened zone in sharp contrast to the unhardened core.

In the adjoining photograph the longitudinal section of a 7 x 1-in. pin has been so tempered. The transverse (circular) section has been cut — as hardened — with a friction wheel. The two shells show the same depth. From the tempered (longitudinal) specimen it can be seen that the method can be utilized to determine easily the over-all hardness pattern of an induction hardened part. (F. V. Horak, metallurgist, Allis-Chalmers Mfg. Co.)

A Tilting Stage for Leveling Metallographic Specimens

When a metallographic specimen is placed on the stage of a microscope it frequently happens that all areas of the field of view are not in focus at the same time. This is not too objectionable for visual examinations, since a slight adjustment in focus may be made while the specimen is being examined; however, for photomicrography, the entire field must be in focus at the same setting.

It is obvious that a device allowing the specimen to be tilted to any desired angle would allow

the field to be adjusted so that it is normal to the optical axis. We have designed such an attachment for our microscope. Illustrated in the accompanying photograph, this leveling device is a simplified modification of the universal stage that has been used on petrographic microscopes. The center ring that holds the mounted specimen is suspended on gimbals; the two axes of tilt allow the specimen to assume any angle desired. The largest of the three rings is seated in the normal stage opening. The adjustment is controlled by two thumbscrews, and the small springs on the opposite side keep the rings in contact with the control screws.

Although in the illustration this leveling device is shown on the inverted stage of a horizontal metallograph, by making a suitable adapter, the leveler may be used also on a microscope with upright stage. A ring in which to seat the leveler may be held by two vertical supports at the ends of the usual metal slide that holds the specimen.

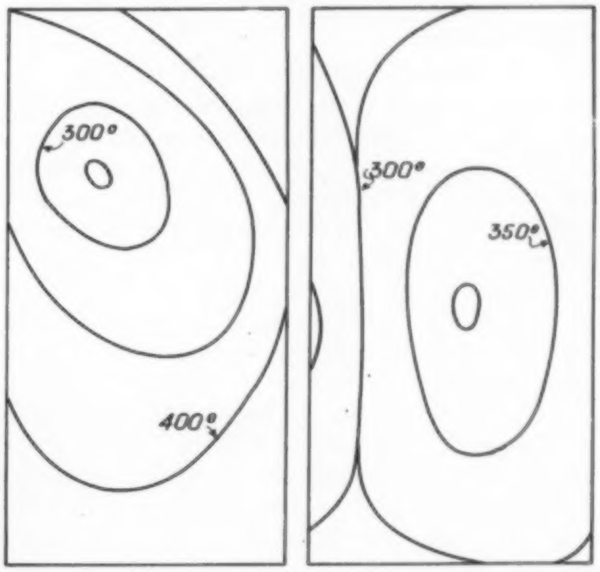
The one disadvantage of this design, of course, is that tilting the specimen will change the distance between the objective and specimen, thus necessitating refocusing, except when the intersection of the two axes of tilt coincides with the optical axis. Although it would be desirable to eliminate this inconvenience, we have not found refocusing too troublesome. (E. C. PEARSON, chief metallographer, Aluminium Laboratories Limited)

Using Tempilstiks for Determining the Heat Losses of a Furnace

IN STUDYING the characteristics of a special high-temperature furnace, some information was sought as to the temperature range and distribution on the outside furnace walls. Exploration with a thermocouple was unsatisfactory because of the impossibility of getting sufficiently close contact on an uneven or painted surface.

The following simple procedure was then used to obtain accurate temperature-distribution curves in a minimum of time.

Chalk guide lines were drawn traversing the furnace wall in four or more directions and intersecting at the center. By the use of "Tempilstiks", the temperature gradients along each guide line were easily found. The point at which any particular Tempilstik melted was measured along the guide line and the temperature and distance plotted on a scaled drawing of the furnace wall. The isothermal points were then connected on the graph, resulting in a contour map of temperature.



Contour maps showing hot spots or cold areas *(see cut)* can be interpreted in terms of heat losses, and the design of the furnace can be revised so that a more nearly uniform distribution of temperature results. (LEO SATZ, metallurgist, Schenectady Laboratory, General Electric Co.)

Removing Carbonate From Copper Cyanide Plating Solutions

ONE of the problems arising in the use of copper cyanide plating solutions is the removal of carbonate from the bath. The accumulation of carbonate is inevitable because of the decomposition of cyanide and the absorption of carbon dioxide from the air.

Most methods for removing carbonate are so difficult or impractical that, in the past, valuable plating solutions often have been discarded and replaced with new solutions. However, we have

found that carbonate can be removed efficiently and economically by adding to the plating solution 0.6 oz. per gal. of calcium carbide for each ounce per gallon of carbonate. The calcium carbide reacts completely with the water to produce calcium hydroxide, which reacts further, and acetylene, which escapes safely through the exhaust system:

$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$$

Although calcium hydroxide is only slightly soluble in water, it does dissolve in the plating solution and thus precipitates carbonate as calcium carbonate:

$$Ca(OH)_2 + Na_2CO_3 \rightarrow 2NaOH + CaCO_3$$

Thus sodium hydroxide is formed in the bath, and the calcium carbide must be added in small enough portions so that the hydroxide content will not be excessive. Theoretically, 0.8 oz. per gal. of calcium carbide should yield 1.0 oz. per gal. of sodium hydroxide.

Certain mixtures of acetylene and air explode, but the exhaust system should safely remove the small amount of acetylene without danger if the carbide is added slowly.

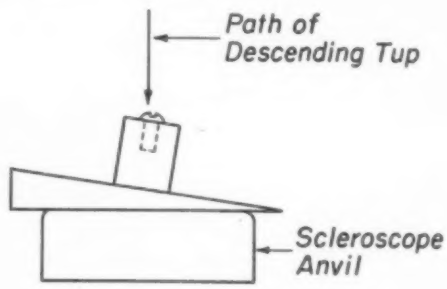
Technical calcium carbide costs $94 per ton or 4.7¢ per lb. The removal of 23 oz. per gal. of carbonate would require $23 \times 0.6 = 13.8$ oz. per gal. of calcium carbide. In a conveyer tank that contains 1600 gal., the 1380 lb. of calcium carbide required would cost $64.86. Technical calcium carbide is approximately 90% pure; the residue consists of free carbon and sulphides, which cause the solution to turn black temporarily. Overnight the black colloidal particles will settle to the bottom of the tank. The calcium carbonate precipitate will occupy about one tenth of the volume of the tank. The sediment should be removed but steel may be plated successfully in the supernatant liquid.

A laboratory test made on 2 gal. of plating solution showed that the calcium carbide (13.8 oz. per gal.) removed 80% of the calculated amount of carbonate and produced 50% of the calculated amount of sodium hydroxide. This inefficiency was probably caused by the fact that the calcium carbonate precipitate contained about 10% unreacted calcium hydroxide that did not dissolve, and that the original calcium carbide was 10% impure. The copper and free cyanide contents remained virtually unchanged. However, some copper was lost as copper sulphide, and this increased the free sodium cyanide slightly. The formation of sodium hydroxide increased the pH of the solution from 9.5 to 14.0. The purified bath produced a brilliant plate. (H. F. Ross, formerly with Delco-Remy Division of General Motors Corp.; now at Battelle Memorial Institute)

Using the Scleroscope for Testing the Depth of Shallow, Hardened Cases

MANUFACTURERS of metal products that require a shallow, hardened case may be interested in a quick and easy method for checking the case depth by means of the scleroscope hardness tester.

Our tests were made only on sheet metal screws, cyanided and then quenched in cold water.



However, the method should be useful for testing many light-case parts and particularly nitrided parts, which typically have shallow cases.

The scleroscope measures the rebound of a diamond-tipped tup that is allowed to fall by its own weight and to rebound from the test specimen. Normally the height of rebound is interpreted as a measure of hardness; the harder the surface of the specimen, the higher the tup will rise in rebounding. We have found that when casehardened parts of *equal* penetration hardness at the surface are tested with the scleroscope, the height of rebound depends on the *depth* of the hardened case. The specimen having the deepest case will give the highest reading on the scleroscope dial. Thus, for surfaces of equal hardness, the instrument can be used to indicate the depth of hardened case. If the penetration hardness of the surface varies, the results will be unreliable.

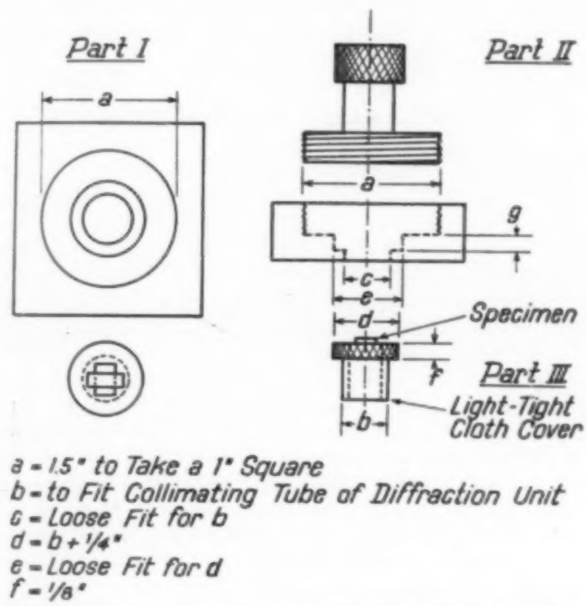
The sensitivity of this method decreases with increasing depth of case. For instance, it is easier to distinguish between cases 0.003 and 0.005 in. deep than between cases 0.013 and 0.015 in. deep. The method is recommended primarily for cases shallower than 0.010 in.

A special fixture will usually be required for holding the specimen while it is being tested. The accompanying cut shows the simple arrangement we used for testing round-headed and oval-headed screws. Flat-headed screws were even easier to test. The shape, weight, and hardness of the fixture affect the results obtained. Therefore it is important not to change supporting fixtures while a series of similar specimens are being tested. (B. Z. BERMAN, The Bermack Co.)

A Camera for Microradiography

IN microradiography it is of the utmost importance that the sensitized surface of the photographic plate be as close to the specimen as possible. This means that the ordinary type of X-ray cassette cannot be used. Also, it is necessary to have the specimen in line with the rays from the X-ray tube.

The accompanying sketch shows a camera that fulfills these two conditions in a convenient way. This camera, designed at the Naval Air Materials Center, is for use with diffraction units having collimating tubes into which buttons of the general shape of Part III are placed. When



Camera for Microradiography

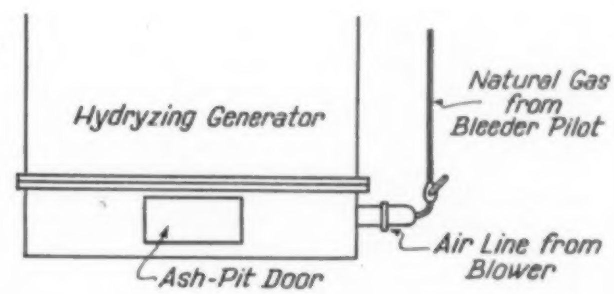
the camera is used for diffraction, the specimen is placed across the rear of a small hole drilled through the button. To use such a unit it is necessary to align the collimating tube with the X-ray beam. After it has been aligned, the tube can be clamped in place with set screws so that it is possible to make an unlimited number of exposures without realignment.

For microradiography, Part III, the button, instead of being pierced with a small hole, has a slit cut somewhat larger than the specimen to be radiographed. The specimen is attached as shown, using water glass as an adhesive. A light-tight cover is put across the open, or projecting, bottom of the button. Originally, a piece of aluminum foil was used as a cover, but it was too dense; good results are now being obtained using a piece of opaqued scotch tape. The button is then inserted in place in the body, Part I, of the camera. The sensitized plate, cut as a 1-in. square, is placed over the specimen, with two or three thicknesses of lens paper between it and the specimen. The threaded closure, Part II, is then turned down, forcing the plate against the specimen. The camera is then light-tight, and can be moved without danger of the plate being fogged. The projecting part of the button is placed in the collimating tube of the X-ray machine, and then the exposure is made. (GERARD H. BOSS, Naval Air Materials Center, Naval Air Experimental Station)

Starting a Hydryzing Generator

IN the Metals Research Laboratory a Lindberg furnace equipped with a hydryzing generator to provide controlled atmosphere is used intermittently for heat treating. Starting the cold generator by the usual method of igniting an oiled rag or wad of excelsior in the ash pit has been found to have several disadvantages, chief of which is the fact that a carbon sludge resulting from the combustion of these materials is deposited in the various pipes and valves in the system, necessitating frequent cleaning.

In order to avoid this troublesome procedure and to eliminate the dirt and smoke associated with starting the generator, the 2-in. pipe through which the air is forced into the generator was



tapped and ¼-in. copper tubing to permit the introduction of natural gas was attached, as shown in the accompanying sketch. In this particular installation, the air and gas meet at right angles so that sufficient mixing results before combustion takes place in the ash pit.

Starting the cold generator is now rapid and convenient since it requires only that the gas-air mixture be adjusted to provide the proper flame. As soon as the charcoal is ignited (about 15 min.) the natural gas is turned off. (PAUL E. BUSBY and CECIL C. BUSBY, Metals Research Laboratory, Carnegie Institute of Technology)

Guided Missiles in the Atomic Age

High Angle Guided Bombs*

THE high angle bomb is dropped out of a bomb bay when the plane has been flying in a straight line toward the target. If the plane continues in the same direction, the bomb seems to remain vertically under the plane until it hits the ground, and the bombardier can easily see whether it is going to the right or the left of the target. However, he cannot tell whether it is going to hit the ground too soon or too late.

To control the flight of the bomb, it is necessary to keep it from rotating about its axis, to correct its azimuth (right and left deflection) and to correct its range.

Stabilization against rotation was achieved in a program during World War II through ailerons attached to the bomb's tail and controlled by two electric-driven gyroscopes, the "free" gyro which returned the bomb to a position at which rudders are vertical, and a "rate" gyro which prevented overshooting more than 3°. Deflections in course and range were prevented (or induced, at will) through rudders and elevators, respectively, arranged as fins projecting from the tail structure. These were moved by servomotors.

Three principal schemes for correcting azimuth and range were studied. One transmitted a picture of what could be seen from the nose of the bomb itself by television to the bombardier. Another was automatic and made use of homing equipment in the bomb, sensitive to heat or light emitted from the target. The third, the one finally used, was the direct sight method. In this, it was necessary to provide the bomb with a flare, ignited by bombardier at any time after take-off. For this and the other remote controls it was necessary to provide radio communication with the falling bomb. The antennae were built into the struts used to stiffen the tail fins, and a radio receiver (a compact superheterodyne) was arranged to select functions by frequency modulations. Many test drops were made while motion pictures were taken from the plane and from the nose of the bomb; these provided a satisfactory analysis of the actual trajectory.

"Azon", direct vision controls in azimuth only, had been recommended for bombing roads and bridges. Azon bomb No. 13 was controlled all the way to the ground and struck the target, a road 12 ft. wide. This bomb was put into production and used effectively in Burma, 3½ years after the initiation of research work. Approximately 150 bridges were destroyed, completely disrupting Japanese communications. Increase in effectiveness is illustrated by the fact that the number of bombs required to destroy a bridge was reduced from 300 or 400 of the standard bombs to six or seven Azons.

For bombs controlled in both range and azimuth (Razon), it was necessary to provide an entirely different tail construction from the cruciform fin structure on Azon, using instead aerodynamic surfaces in the form of two shrouds, one set some distance ahead of the other. Viewed directly from the rear these shrouds looked like short sections of octagonal down-spouts. Control surfaces were built as flaps on the trailing edges. The electrical and control apparatus contained in the tail compartment required very little extra engineering.

Razon was not used in combat, although it was in production at the end of the war. Experimental drops from 15,000 ft. indicated an accuracy of 45 ft. in range and 15 ft. in azimuth.

*From talk before Franklin Institute, Oct. 15, 1947, by L. O. Grondahl, consultant in research, Westinghouse Air Brake Co. and Union Switch and Signal Co.

V-2 and Future Guided Missiles†

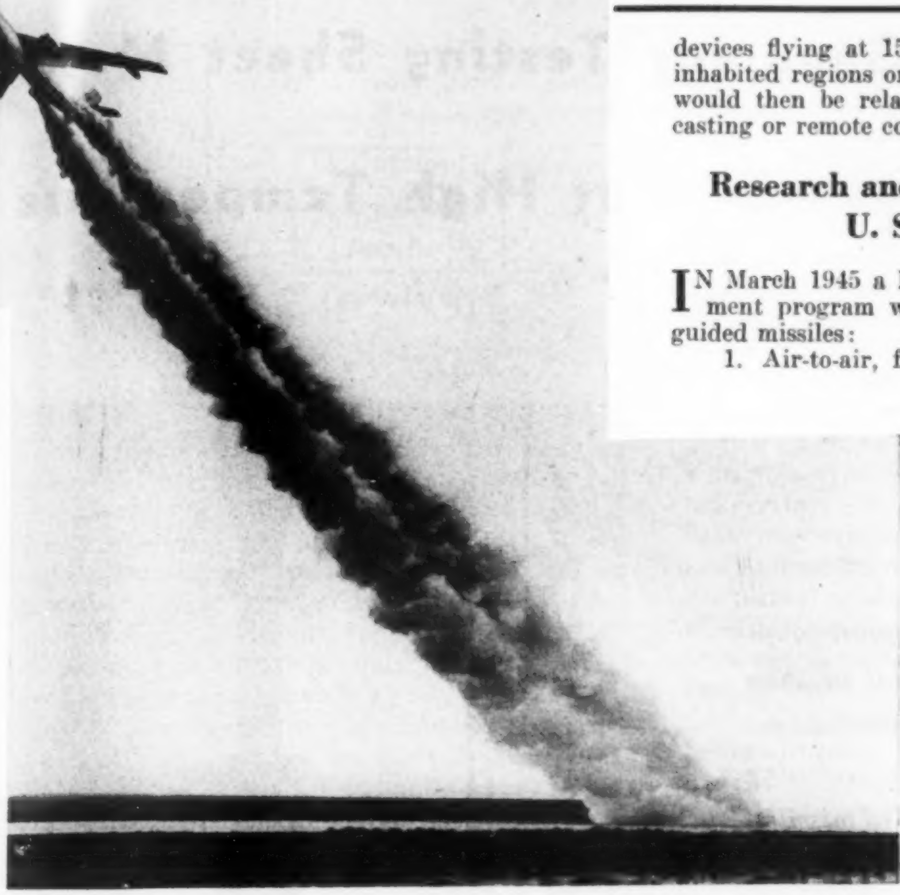
THE development of the V-2 was part of a German program starting in 1930 which brought some 130 rockets, guided missiles and assorted devices to various stages of developmental and operational use. Actual work on the V-2 started about 1940; the first successful firing was in October 1942; the range was 170 miles. Its development cost 18,000 man-years; some 65,000 engineering changes were made after the first successful flight. A total of 3165 V-2's were launched against England, Antwerp and Continental targets; they were being manufactured at the rate of 96 a day at the end of the war. It was not until our technicians examined this program that it was realized how narrow was our margin at the armistice and what losses a six months' continuation of the war would have caused the Allies.

The V-2 is 46 ft. long, 65 in. in diameter, weighs 7000 lb., carries 2000 lb. useful load (war head), and 28,000 lb. of fuel. It is launched vertically. Within 60 sec., 1220 gal. of 75% alcohol and 1220 gal. of liquid oxygen are forced into the combustion chamber; the gas exit velocity of 7000 ft. per sec. generates a thrust of 60,000 lb. At the end of that time the missile is flying at about 3600 miles per hr. It is launched vertically and guided by carbon vanes in the blast and aerodynamic tabs on the fins, all controlled by gyros through electro-hydraulic servomechanisms. After burnout, the missile is directed in the required azimuth by preset timing equipment and thereafter has the path of a projectile, because control surfaces are returned to neutral position.

Some 35 V-2's have been launched at 14-day intervals at White Sands Proving Ground in New

†From talk before Army Ordnance Assoc., June 9, 1948, by C. F. Green, consulting engineer, Aeronautic and Ordnance Divisions of General Electric Co.

Presentation of verbatim extracts from important contemporary documents concerning atomic energy does not imply that the Editor agrees with the opinions quoted, nor that they are expressions of A.S.M. policy.



Mexico. A maximum altitude of 114 miles has been attained. The war head is occupied by equipment for observing conditions in the upper atmosphere, for securing aerodynamic data at very high speeds, and for transmitting this information to the ground.

The guided missile must reach out long distances, locate a target and then demolish it. It must also handle stationary or moving targets, be insensitive to enemy "jamming", and have accuracy at least equivalent to artillery fire. Great and successful effort is now being put into the perfection of such weapons.

Motor developments include improvements in combustion chamber and venturi, in fuel mixing, and new fuels. Guidance is the greatest problem; there is no point in building complex equipment to obtain "near misses". To secure higher accuracy in any type of guidance system — preset, course-seeker, beam-rider, command or homing — radar, gyros, accelerometers, computers and servomechanisms must be greatly improved over those available at present.

Study has shown that the anti-aircraft missile and the anti-missile missile are not impossibilities but can be achieved if problems of search, early warning, speedy data transmission and evaluation can be solved.

Basic principles are known of vehicles which are orbital satellites. Only funds and time are necessary for them to become realities. Four such devices flying at 1500-mile elevation will cover all inhabited regions on the earth by line-of-sight, and would then be relay centers for television, broadcasting or remote control.

Research and Development by the U. S. Air Force‡

IN March 1945 a long-term research and development program was initiated into four types of guided missiles:

1. Air-to-air, for air combat, to be guided to their targets automatically and to have a range much greater than that of present armament.
2. Surface-to-air, for use against invading air forces and ultimately against enemy missiles.
3. Air-to-surface, for bomber strikes, remotely and accurately controlled from launching aircraft outside the defended area.
4. Surface-to-surface, primarily to carry an atomic war head 5000 miles at supersonic speeds. Since there is no existing defense against this type of weapon, it is essential that the United States be the first to develop it.

Successful flights have been made by "drone" aircraft, equipped with television and controlled by radio from mother planes 25 miles away. Control from distances up to 100 miles away is believed to be within present capabilities. Flights from Hawaii to California, during which bombs were dropped from crewless planes by remote control, are forerunners of accurate employment of long-range guided missiles.

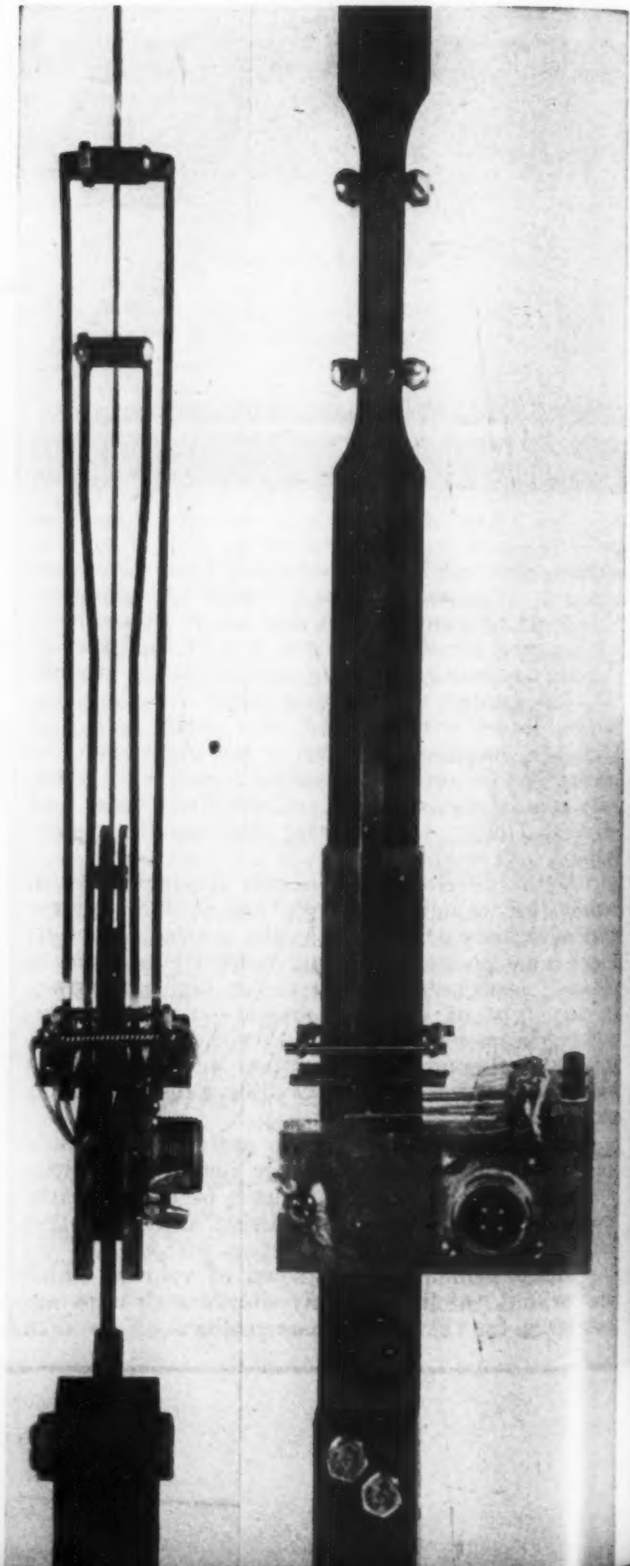
Concurrent with this is the firing of the JB-2, an American ramjet missile similar to the German V-1, but having guidance devices for remote control over a 150-mile flight. (At present the ramjet appears to be the correct power plant for supersonic flight of missiles for longer ranges than rocket propulsion can reach. A special form known as "pulse-jet" gives better performance than the ramjet up to a speed of 400 miles per hr.)

A signal event in remote guidance and control occurred in September 1947 when a Douglas C-54 with electro-mechanical "brain" took off at the push of a button from Newfoundland, flew the Atlantic 2400 miles and landed at a British airfield near London. Two surface ships transmitted the necessary bearing beams to keep the airship on its course. A beam at the English airfield turned it into the glide path, lowered the landing gear and braked it to a stop.

‡From report of Gen. Carl Spaatz, retiring chief of staff, U. S. Air Force, June 30, 1948.

Strain Gage for Testing Sheet Metal at High Temperature

By Glen Guarnieri
and James Miller
Research Metallurgists
Cornell Aeronautical Laboratory
Buffalo, N. Y.



Tensile, creep and stress-rupture properties of high alloy material in sheet form are required by designers and engineers in the program for perfecting jet engines, rockets and guided missiles. The authors describe an extensometer and instrumental setup that utilizes eight strain gages, so mounted as to cancel out numerous variables and record a single equated value at any instant.

IN A STUDY of the load carrying ability of various sheet stock alloys at high temperature, instrumentation has been developed for conducting tensile, creep, and stress-rupture tests. The objectives of such tests have been concerned primarily with the evaluation of materials for relatively short life — applications such as encountered in guided missiles, rockets, and jet engines. The variables of common interest to such investigations are stress, temperature, strain, and strain rate. Basic units of equipment have been constructed or assembled for measuring and controlling these variables.

While conventional types of apparatus have been used for loading, heating, and controlling the

Fig. 1 — Assembly of Test Piece, Lower Grip, Extensometer Arms and Cantilever Strain Gage

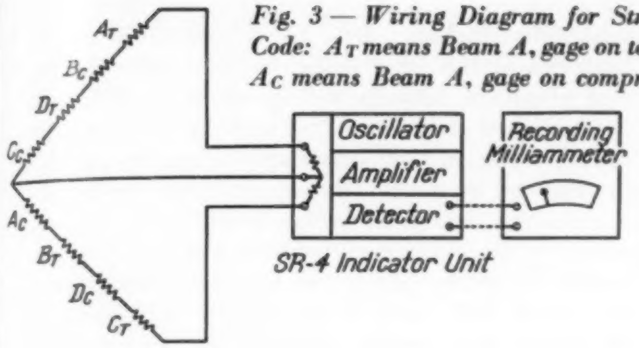


Fig. 3 — Wiring Diagram for Strain Gages. Code: A_T means Beam A, gage on tension side; A_C means Beam A, gage on compression side

temperature of the specimen, a strain measuring system has been designed and constructed for determining the elastic modulus, proportional limit, yield stress, and creep deformations of sheet stock at temperatures up to 1800° F. This strain measuring device, while of light weight, is sufficiently rugged to permit routine and accurate measurement of 0.00010 in. change in gage length over a range of approximately 0.2 in. (10% in 2 in.).

This instrumentation was originally developed as part of a test program for the Bureau of Ordnance, and has been modified and improved for work sponsored by the Bureau of Aeronautics and the Office of Naval Research. Thanks of the authors are due to those organizations for clearance of this information for publication.

The general arrangement of test piece, lower grip, extensometer arms and cantilever strain gage is shown in Fig. 1. A conventional tubular furnace, electrically heated, surrounds the test specimen for its full length; the extensometer arms extend through a shield at the bottom of the furnace.

Fig. 2 — Cantilever "Beams" A to D and Mounting

It is obvious that a change in the length of the specimen on its gage length results in a change in the relative position of the lower ends of the extension arms. These arms (made of Type 310 stainless steel) grip the specimen through knife edges; the outer arms are attached to the upper end of the gage length and the inner arms to the lower end. Thus, the strain in the 2-in. gage length is represented by the relative motion of these arms. Since all tests conducted with this type of extensometer are at a steady temperature (maximum variation of ±3° F.) negligible errors are introduced due to expansion and contraction of the extension arms. Such errors are further minimized by the fact that one pair of arms acts as a reference for the other, and tends to cancel out length changes due to any temperature variation.

A cantilever "beam" assembly which engages the extensometer arms is used to detect their relative motion. It is shown in clearer detail in Fig. 2. SR-4 strain gages, attached to both the tension and compression side of each of the four beams near the fixed ends, serve to indicate changes in beam deflections due to specimen elongation. When the SR-4 gages are connected as shown in Fig. 3 to complete the bridge circuit of a Baldwin-Southwark SR-4 strain indicator unit, the amplified unbalanced current in the bridge is a measure of the strain in the specimen gage length.

Consideration of the circuit arrangement of the SR-4 wire gages (Fig. 3) will reveal that the gages on each pair of beams (A and B, or C and D) electrically oppose each other so as to produce a net change in resistance proportional to the difference in deflection of the two beams of each pair, and this net change is electrically added to give a final circuit unbalance that is proportional to the average gage length extension of the specimen.

A Baldwin-Southwark SR-4 strain indicator, which combines the necessary oscillator, amplifier, detector, and balancing controls in a single portable unit, has been used in conjunction with the cantilever strain gage bridge circuit. The unbalanced current output may be read directly on the meter of the strain indicator unit or — as is done for controlled strain-rate tension tests — supplied to a recording milliammeter (Esterline-Angus). When using the bridge circuit in its unbalanced condition for recording strain, linearity of output signal versus specimen strain is limited to about 0.4% extension on a 2-in. gage length, so it becomes necessary to rebalance the circuit when

this value of strain is reached. Where the bridge is maintained manually in balance, continuous strain readings may be made from the calibrated balancing dial of the SR-4 strain indicator unit up to the limit of the extensometer system.

Calibration — Determination of the sensitivity factor of the cantilever gage unit (inches of beam deflection per dial division) is accomplished by deflecting the beams known distances with a micrometer and noting the resulting change in meter or dial reading. Close agreement was realized between the experimentally determined value of sensitivity and that calculated according to the cantilever beam formulas. In order that both pairs of extensometer arms may be truly averaged in the bridge circuit, it is necessary that the individual sensitivity of all four beams be equal. This adjustment is made during assembly of the gage and is controlled by varying the beam span. During the past eight months in which two of these gages have been in use, frequent calibration checks have revealed their high degree of stability and freedom from change in sensitivity.

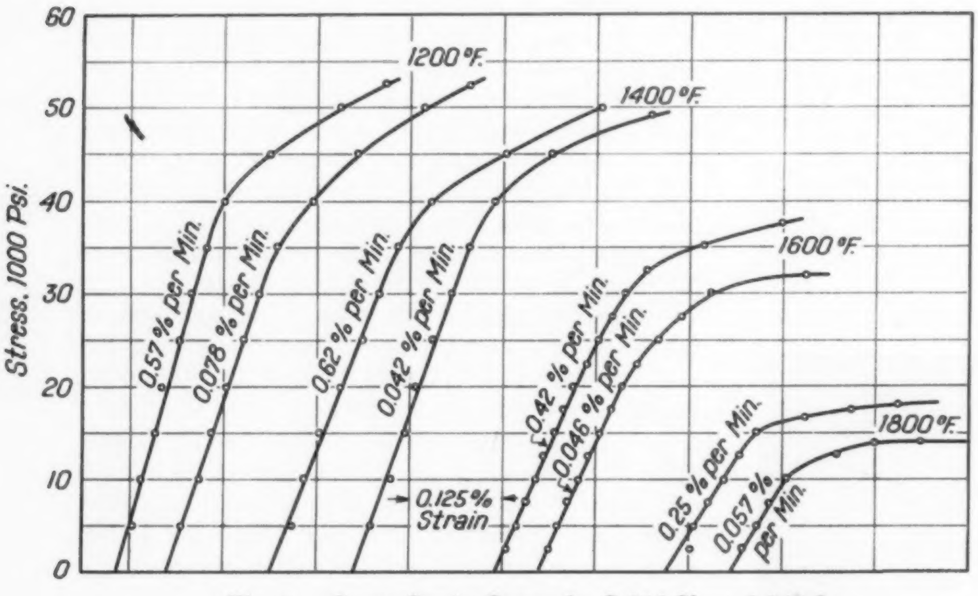


Fig. 4 — Stress-Strain Curves for S-816 Sheet, 0.042 In. Thick, at Various Temperatures and Strain Rates

In conducting tensile or creep tests at 1800° F., sufficient heat is carried through the specimen holder to the strain gage unit to raise the gage temperature to approximately 150° F. However, no change or drift in sensitivity could be detected by calibration tests conducted on the strain gage while at this higher temperature.

When the system is used for automatic recording of strain, the bridge circuit is operated in its unbalanced condition. One precaution must then be observed in regard to determination of sensitivity factor. Due to deterioration of the batteries of the SR-4 indicator unit, its oscillator and amplifier outputs will be altered, giving rise to decreased sensitivity (for unbalanced condition only). The *actual* sensitivity factor is quickly determined by noting the output-meter reading for a standard degree of bridge unbalance, as measured by the calibrated balancing dial. Over the useful operating life of the batteries, the sensitivity factor will vary from 0.00010 to 0.00013 in. deflection per meter division for unbalanced bridge operation. When the bridge is maintained in its balanced condition, its sensitivity is independent of battery condition.

Operation — The cantilever strain gage system has provided a satisfactory means of conducting high-temperature tensile tests at controlled rates of strain. By recording the specimen strain on an Esterline-Angus meter, a graph showing strain versus time is obtained. Through the use of an auxiliary margin pen actuated by a solenoid, loads are registered manually on the same paper at selected intervals so that a simultaneous record of load, elongation, and time is made.

While the specimen is being loaded elastically, a constant strain rate will be maintained on its gage length for a given head speed of the tensile machine. However, as the specimen begins to deform plastically, it becomes necessary to reduce the head speed in order to maintain the same strain rate. The operator accomplishes this by viewing the recording of the time-deformation trace through a plexiglas plate on which are engraved a set of parallel lines adjusted to the slope corresponding to the desired strain rate.

Typical stress-strain diagrams plotted from the recorded data for an S-816 sheet material (0.042 in. thick) are illustrated in Fig. 4.

The same extensometer system has been used for continuous measurement of strain in constant load, high-temperature tests of relatively short duration. For the long-time creep test, it would be necessary to substitute a regulated d.c. power source for the batteries of the indicator unit if a continuous strain record were required.

Notes at the Convention and Elsewhere

By The Editors

AFTER listening for months to conversation about the high price of exhibiting and to much damning of booth builders for highway robbery, was gratified to find the National Metal Exposition a decorative thing of beauty. Were I a reporter for a trade magazine catering to the exhibition field I probably could resist the temptation to sling around superlatives describing such masterpieces as those of Union Carbide and Carbon subsidiaries and Westinghouse. But such a reporter could not help commenting on a professional job done by an amateur. (How often the hams show the way!) Some five months ago Clarence Broner, sales engineer for Sciaky Bros. — the makers of improved resistance welders, you know — blessed with a hobby for woodwork and a good design, started to build his own 60-ft. booth in his basement shop, and at last it emerged, a creation of masonite, glass, velvet and leather, good enough to stand comparison with the best, and at a cost that defies competition. Likewise such a reporter would undoubtedly spend much of his allotted space describing the visualization of 75 years of progress in alloy steel that occupied the entire stage in the Auditorium. Conventions and expositions have had slogans without number, but here, for once, the slogan was given a visual and audible body in exhibits from all the major consuming industries showing equipment before and after refining and perfecting the design with alloy steel — all supplemented with mammoth video telling the entire story. The A.S.M. is to be congratulated for its friends. Why else should International Nickel's Bob Wheeler and his committeemen devote so many hours to organizing, creating and mounting such a revealing show?

"COMPENSATION" is the word that Emerson would use. It would describe the reward for mounting the metallographic exhibit — the aesthetic pleasure of examining so many fine examples of photographic skill, and the mental stimulation of conversation with the expert judges. Inquiring about the absence of any work done with ultraviolet light, was informed that the quite desirable resolution of fine detail gained by short-wave exposure was counteracted by the extreme difficulty of getting an accurate focus (almost by cut-and-try methods, exposing successive negatives) and the long exposure time — hours, even, for the available radiation sources of weak intensity. The consensus of the experts also was that the electron microscope (useful though it has been for studying the form of very fine particles and powders) has yet to solve any microstructural problems not already all-but-certain from optical studies. Earliest stages of grain germination in precipitation hardening, for example, involve particle sizes on the same order of magnitude as the grain size of the material forming the replica. The results, therefore, are open to serious question: Is what we see the structure of the metal or is it the structure of the replica?

WHEN a physicist discusses the characteristics of an instrument that he has invented, the metallurgical audience is likely to hear some plain talk, and so it was when Floyd A. Firestone spoke with exceptional clarity in presenting the 1948 Mehl Lecture of the Society for Non-Destructive Testing. Those who read the issue of *Metal Progress* for September 1945 will remember the principles of Dr. Firestone's supersonic reflectoscope, an instrument for nondestructive testing and measuring by means of sound waves. The instrument shouts "yoo hoo!" into a piece of metal and listens for an echo. Any crack in the metal will cast an acoustical shadow that can be located by means of electrical devices similar to those used in radar. The reflectoscope has been used industrially for several years and the basic technique is becoming widely known. The Mehl lecturer discussed some of the tricks that are possible and may in the future be put to use in special applications. The standard techniques depend primarily on reflection. The newer techniques depend also on other properties of sound waves — refraction, scattering, resonance, and polarization. In addition to its use as a flaw detector, the instrument can sometimes measure

the elastic constants of metal, the average grain size, or the difference in properties of wrought products in different directions, and in maintenance work to detect the beginning of fatigue cracks in machine parts in places that are inaccessible except to sound waves transmitted from the reflectoscope.

INTEREST in the scientific and ultra-technical aspects of metallurgy shows no signs of abatement, to judge from the size of audiences at the formal sessions. (Some 60 metallurgists and 40 librarians even came from as far as Los Angeles to spend an earnest afternoon over the problem of devising an adequate system just to classify this ocean of knowledge.) And it is interesting to see some strange elements reappear at intervals, as though to demand attention to their unique capacity for good — or harm. For example, do you remember how zirconium was studied after World War I, and how Colonel (then Captain) Ritchie and the late Frederick Becket showed how normal steel could be made without manganese if only enough zirconium were available to take its place? It "fixes" the sulphur. Later, C. L. Altenburger added it to steel to make a variety with unique low-temperature toughness. It seems also to "fix" the nitrogen. Then zirconium was found to give fine grain and high-temperature strength to magnesium alloys. Now General Electric's R. H. Harrington adds 0.35% to commercially pure aluminum and finds the temperature for a softening anneal raised to 1110° F. with a corresponding improvement in stress-rupture times at moderate working temperatures. A. L. de Sy, professor of metallurgy at the Belgian University of Ghent, now visiting in the United States, says it is one of the elements which are added to make ordinary white iron solidify with so many nodules of graphite that subsequent annealing to true malleable is only a matter of a few hours. The metal itself, in wire form, is one of the best "getters" of residual gas in electron tubes. Lastly, studies of the pure metal show that it absorbs relatively few neutrons, and so is a possible substitute for the dangerously toxic beryllium as a moderator or as metal accessories in an atomic energy pile.

LIFE in the pre-A.S.M. days must have been pretty easy for the steel expert. All he had to do was to remember a few "principles" and apply a lot of precepts. The precepts saved his life, for the principles degenerated into hypotheses, and then gifted experimenters, like Campbell Memorial Lecturer Morris Cohen, gradually chiseled all sorts of inaccuracies from them. With fact and appealing logic he discussed the curious change from austenite into martensite — or rather the curious reluctance of all the austenite in hard steel to engage in this reaction. How much simpler it was, in the days before subzero refrigeration, when the hardener merely trusted his assorted potent brines! Envy the metallographer who knew martensite and troostite but knew not bainite. However, with men like Cohen around it's just no use to mourn for the good old days; we must face the Facts of 1948 and all their "separation processes" and "transformation centers" either large and active or small and inactive, either packed with energy poised to spring or sleeping unmindful of their strength! One warning: To enlist under the Cohen standard some mathematics must be remembered and "surface energy" and "entropy" be more than just words for things never understood.

AMERICAN Welding Society's Adams' Lecture, by G. E. Claussen, considered something "ignored, because we knew nothing about it" — namely, the influence of the slag originating from the electrode coating on the deposited weld metal. The lecturer likened arc welding with bare electrodes to the bessemer steelmaking process with its intimate contact between metal and air and the formation of relatively little slag. The process using covered electrodes forms steel under twice as much slag as exists in the openhearth, yet contact between small globules of metal and enveloping slag is so much more intimate that welding is more like the Aston or the Perrin process for refining iron by atomizing it in molten slag. These analogies are both defective because metal under the welding arc is so much hotter. Nevertheless, using the same principles of physical chemistry as rule ordinary steelmaking processes, Dr. Claussen found that the partition of sulphur between slag and weld metal was about the same as theoretically predicted. Phosphorus partition was not nearly so complete — apparently the brief time the metal is liquid is not long enough for even an approach to equilibrium. Experimental results for oxygen were inconclusive. Indeed, the lecturer cautioned his audience that his tests were exploratory rather than conclusive; they applied only to three specific electrode types, and did not consider one of the prime constituents of all the tested coatings — namely, moisture.

WHEN the digestive system begins to digest itself, the result is ulcers. And when a theory of metals begins to dissolve in its own mathematical juices, the result is a sort of metallurgical biliousness. Ulcers may sometimes be

cured by changing the patient's diet or quieting his thoughts. Likewise, some forms of metallurgical biliousness may be cured by a change in diet that includes frequent, large doses of experimental facts. The theory of plastic deformation of metals has lately been suffering from mathematical convulsions, based on compound and interlocking assumptions. But some of the curative facts were supplied at the Convention in sessions held by the American Society for Metals and the Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers. The data of Dorn concerning the effects of mechanical-thermal history on the flow stress and strain hardening of metals (together with some recent results by Orowan in England) should go far toward demolishing the so-called mechanical equation of state recently proposed. Both Dorn in California and Orowan in England have shown that the stress-strain behavior of a metal depends on the previous thermal and mechanical treatment the specimen had undergone — something suspected by metallurgists for quite a long time. The A.S.M. Seminar on the Cold Working of Metals and two A.I.M.E. sessions on plastic deformation gave voice to new theories as well as new data. Eventually, some of the semantical, mathematical and physical concepts now circulating among the theorists may be helpful to the metal industry. The pragmatic test to which all these ideas must finally conform is the test of reality, the test of experimental facts.

CONVENTION FOOTNOTE (apropos of something or other): Manufacturers of welding devices put price signs on their equipment. Remarkably cheap, too, they seemed to be in this day of the three-dollar breakfast.

Have Some Aluminum?

ONCE, last year in Wyoming, at the end of a hard day's ride, I reached the main gate at the home ranch and found to my joy that the creaking timber barrier that needed a 100-lb. lift even to unlatch it had been replaced by a silvery aluminum gate that slid aside without even requiring the horseman to dismount. Such minor personal recollections lend importance to the efforts of men at Reynolds Metals Co. to develop other new uses for aluminum, even though there isn't now nearly enough metal to satisfy old customers. Undoubtedly the day will come. . . . . . While talking with Roy Roshong, product manager of Reynolds' rod, bar and structural division, gathered that the present shortage in ingot tonnage is due to insufficient power for the nation's reduction plants. Since the war, also, the relative loads on finishing departments have changed. Instead of extremely high-strength alloys, present demand is for metal of moderate strength and maximum utility, as related to formability, free machining, or weldability. The sheet, bar, and extrusion mills are continuously busy on items for buildings, machinery and utensils generally — including ranch gates. To a graduate from a steel mill the rolling of aluminum is fascinating — a billet that doesn't look like it's hot, even at first, is rolled and rolled and rolled; it doesn't radiate much heat, and what heat is lost is largely regained by the work of rolling.

During the war, Reynolds promoted the idea of shipping blanks to its customers rather than coils, thus retaining most of the scrap within the mill where it could be reclaimed immediately. A logical extension of this idea brings about the manufacture of such items as tubs for washing machines; a complete production line turns these out by the thousand. You'd be surprised at the number of "clinker type" aluminum boats (12 ft. long, 54-in. beam) that are being sold, but no waterman could deny their beauty and trim. More prosaic is the line of standardized truck bodies, five parts nested in a crate, requiring only to be riveted together at corners and bolted to the chassis. Another plant at Louisville cannot keep up with orders for roofing, siding, gutters and downspouts in numerous designs, textures, chemical finishes and colors. Some of the metal for such applications in the building trades is of alloy diverging slightly from standard analyses, reclaimed and refined in the plant described by George Birdsall in *Metal Progress* for December 1946. Bulky scrap admixed with heavy metal is handled here with ease and dispatch; even baled foil trimmings present no problem.

Atom; АТОМ

AMONG other things coming to the editorial desk is a publication from Lake Success giving in the five official languages of the United Nations (English, Français, Русский, 文中, and Español) a polyglot glossary of technical terms in use in the field of atomic energy. We welcome it as an exhibit of the need of all people to understand each other when talking about the atom, atome, атом, 原子, átomo. Of the 200 terms, the Russians seem to have a different word or a different spelling for each — which seemingly agrees with their penchant for disagreement. But there should be some hope as long as the real fundamental *is* the same: atom; атом.

Low-Temperature Impact of Annealed and Sensitized 18-8

By Erwin H. Schmidt
Metallurgical Engineer
A. O. Smith Corp.
Milwaukee, Wis.

During the war, trouble developed in some reactors made of 18-8 stainless (0.06% carbon) and used in a synthetic butyl rubber plant in cycles from +150 to −150° F. These reactors consisted of two shells, one inside the other, connected by several cross-overs, welded in. Leaks occurred within two months near welds, and a combination of "weld decay" and cold work was suspected. The affected areas were locally annealed and the trouble stopped. Only recently the author studied the matter at the University of Wisconsin in postgraduate work performed under an arrangement whereby certain employees of A. O. Smith Corp. are aided by the firm in securing advanced degrees.

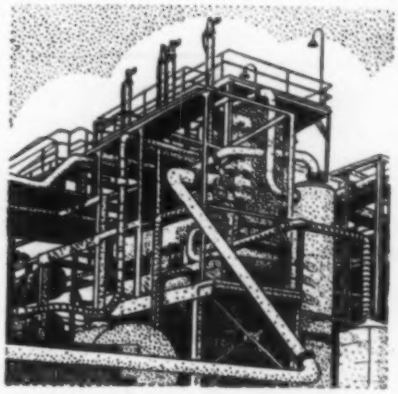
IT IS WELL KNOWN that cold work generally alters the physical properties of steel and manifests itself in increased hardness, and in increased brittleness as measured by the impact test. Any reduction of cross-sectional area by cold deformation will involve stressing beyond the yield point, and the amount of cold work is directly proportional to the reduction of area. Graham and Work have developed a work-brittleness test in which a round tapered steel specimen is drawn through a die and then notched for impact testing. Their method has been modified for use in this study of cold work on 18-8 alloys.

It is also well known that engineering structures are subject to complex stress systems, in most instances two- and three-dimensional. Kinzel and his associates are of the opinion that notched-bar impact strength is a criterion of the ability of a metal to distribute two- and three-dimensional stresses, and that it also is an indication of the material to withstand notch fatigue. For this reason it is felt that impact tests would best evaluate the austenitic alloys in low-temperature applications such as in the synthetic rubber process. Crafts and Egan have also shown that the notched-bar impact test is a suitable standard for estimating the resistance of *unnotched* metal to brittle failure under static load.

The impact value of a given test bar depends on the amount of metal deformed. Hoyt, in a series of articles on notched-bar testing during 1936 in *Metals and Alloys*, notes that the "notch effect" occurs in all materials; it is only certain of them which, though normally ductile, exhibit notch brittleness. A metal which is "notch sensitive" breaks sharply by simple extension of the notch as a crack; if the metal is not notch sensitive the metal at the base of the notch flows slightly in a ductile manner and reduces the notch effect by increasing the radius of the notch. He has also shown that bars absorbing high energy per unit area during the test break with a fibrous fracture, while low energy absorption is associated with a crystalline fracture.

The Charpy impact test bar was selected because it is a standard, and test results may be directly compared with other data. Furthermore, uniform notch conditions can be economically reproduced. There is evidence to indicate that the keyhole notch is definitely superior to the V-notch

with respect to reproducibility of the notch contour, reproducibility of the energy values, and revelation of the transition zone in temperature-impact relationship.



Materials Tested and Procedure

To determine the effect of cold work upon the impact notch toughness of 18% chromium, 8% nickel stainless steel, austenitic alloys of Types 302 and 304 (0.14 and 0.07% carbon, respectively) were compared in the fully annealed and in the sensitized conditions. Round bars (¾ in.) were taken from warehouse stock, annealed and machined as shown in Fig. 1. Following cold deformation, Charpy keyhole notch impact tests were made at room temperature, at −150 and at −300° F., as will be described at length.

The chemical compositions were as follows:

	Type 302		Type 304	
	Specification	Actual	Specification	Actual
Carbon	0.08 to 0.20	0.14	0.08 max.	0.07
Manganese	2.00 max.	1.08	2.00 max.	0.70
Silicon	1.00 max.	0.29	1.00 max.	0.77
Phosphorus	0.04 max.	0.012	0.04 max.	0.012
Sulphur	0.03 max.	0.012	0.03 max.	0.018
Chromium	17 to 19	18.43	18 to 20	18.69
Nickel	8 to 10	8.90	8 to 11	9.30

Machining — Cold work was developed uniformly in a machined test bar 15 in. long (Fig. 1) by pulling it through a sizing die having a bore of 0.562 in.

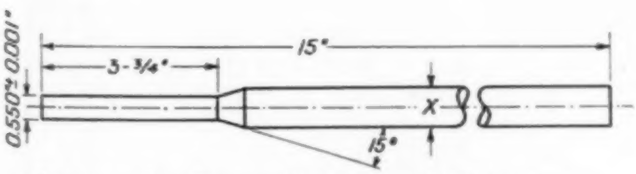


Fig. 1 — Test Bars as Machined and Before Drawing Through 0.562-In. Sizing Die. Diameters to induce various amounts of cold work are:

X, Original Diameter	Final Diameter	Cold Work
0.562 ± 0.0005 in.	0.562 in.	0.0%
0.577 ± 0.0005	0.562	5.0
0.594 ± 0.0005	0.562	10.0
0.611 ± 0.0005	0.562	15.0
0.630 ± 0.0005	0.562	20.0

Heat Treatment — Prior to any cold working all bar stock was heat treated by water quenching from 2050° F. These bars were then carefully machined to the required initial diameter.

Since the object of the test was to determine the properties of the material both in its best condition and in the worst condition that might occur alongside a fusion weld, half of all the bars were "sensitized". As is well known, the quenched austenitic 18-8 alloys are in a metastable condition, in the sense that, if heated in the region of 1000° F. some of the carbon, especially on the grain boundaries and twinning planes, will come out of the uniform solid solution (austenite) and form carbides with surrounding chromium and iron atoms. This action renders the metal liable to selective attack along those surfaces by certain severely corrosive solutions. The test for "sensitivity" is known as the Strauss test and consists of boiling the sample for specified times in a solution of copper sulphate and sulphuric acid. Selective acid attack may be determined by loss in ductility in a tensile or a bend test, or by microexamination.

On the basis of bend tests after 72-hr. boiling in the test solution, it was decided that coarsening of the austenitic grain size at 2250° F. and water quenching, followed by 100 hr. at 1020° F. would produce the severest degree of sensitization in the low-carbon, Type 304 alloy — an alloy designedly resistant to this undesirable phenomenon. No difficulty was experienced in sensitizing the higher carbon Type 302 stainless steel; coarsening the Type 302 at 2250° F. and sensitizing for 2 hr. at 1200° F. resulted in a 0° bend test.

It should be emphasized that sensitization followed final machining of all test pieces.

Impact Test Pieces — Following the above heat treatments, all specimen bars were drawn through the die at room temperature. The cold worked round bars were then milled into squares and cut into five standard 0.394 x 0.394 x 2.165-in. Charpy bars. Following surface grinding, these were given a keyhole notch by using a No. 47 drill in a drilling fixture; the slot was carefully cut on a band saw.

Impact tests were made in quintuplicate at +70° F., −150° F., and −300° F. Subzero temperatures were achieved in an insulated chamber. For −150° F. bars were immersed in liquid pentane; this container in turn was surrounded by liquid nitrogen and the whole assembly placed within the insulated chamber precooled with solid carbon dioxide. The −300° F. temperature was main-

tained by using liquid nitrogen in an insulated chamber. After being in the coolant for one hour, the pieces were removed and broken; at no time did the transfer require more than 5 sec.

Test Results

Tables I and II contain summaries of the impact tests.

Following the impact tests, hardness tests were made on each broken Charpy bar, using the Rockwell A-scale (60-kg. load with diamond "brale" indenter). These hardness averages, converted (for specimens tested at room temperature), are as shown in Table III, at right, below.

All broken specimens were stacked in order and photographed. One of the four photographs is reproduced in Fig. 2. Sensitized Type 302 shows clearly the growing preponderance of crystalline over the fibrous fracture as degree of cold work increases (see the group tested at −150° F.) and as temperature is lowered. Similar conditions existed in the tests on sensitized Type 304 steels. Fibrous, ductile fractures characterized *all* broken bars of both types when annealed, irrespective of testing temperature.

Effect of Welding — An attempt was made to compare the actual coarsening and sensitization which accompany welding of these two alloys with the laboratory heat treatment given the specimen bars, since it was impractical to make impact tests on actual heat affected areas of stock subjected to cold work. Consequently, material of each type was hot forged into ¼-in. strips and then water quenched from 2050° F. A full penetration weld using 19% chromium, 9% nickel electrodes was then made. Samples of the weld cross section were then subjected to the Strauss test in the as-welded condition. Bend tests of the heat affected areas of the stock indicated that the Type 302 stainless steel had become sensitized during welding, while Type 304 stainless had not.

Microscopic Examination

Transverse cross sections of the cold drawn specimen bars have been polished and then etched with a modified aqua regia solution containing an excess of cupric chloride. Comparisons were made on the

Table I — Impact Tests on Type 302 Steel (0.14% Carbon)

Degree of Cold Work	Annealed Specimens		Sensitized Specimens	
	Range	Average	Range	Average
	Tests Made at Room Temperature			
0%	74.7 to 83.5	79.7	69.6 to 100.3	82.7
5	55.2 to 64.8	60.5	60.2 to 66.5	62.7
10	52.2 to 57.4	54.4	51.0 to 56.6	54.6
15	47.9 to 53.1	50.6	52.1 to 54.7	53.3
20	45.4 to 49.6	46.9	42.4 to 49.5	45.1
	Tests Made at −150° F.			
0%	69.0 to 72.1	70.9	41.2 to 47.6	43.3
5	57.4 to 65.5	60.9	40.3 to 51.4	44.7
10	51.2 to 57.2	55.1	36.5 to 45.1	41.6
15	48.4 to 53.3	51.1	28.0 to 30.3	29.1
20	42.6 to 51.5	46.7	21.7 to 25.6	23.5
	Tests Made at −300° F.			
0%	58.1 to 76.6	66.5	10.0 to 12.2	10.7
5	53.1 to 67.2	59.3	10.7 to 11.9	11.2
10	49.6 to 55.4	52.5	10.0 to 11.9	10.7
15	43.9 to 52.6	49.9	8.9 to 10.0	9.6
20	42.6 to 45.9	43.7	7.8 to 8.4	8.0

Table II — Impact Tests on Type 304 Steel (0.07% Carbon)

Degree of Cold Work	Annealed Specimens		Sensitized Specimens	
	Range	Average	Range	Average
	Tests Made at Room Temperature			
0%	69.4 to 80.8	75.6	76.6 to 86.6	81.1*
5	56.5 to 76.8	65.5	61.1 to 69.6	65.4
10	52.9 to 59.3	56.0	54.7 to 65.5	59.6
15	51.2 to 54.7	52.3	54.5 to 60.6	56.1
20	47.8 to 52.4	50.1	46.9 to 56.5	50.7
	Tests Made at −150° F.			
0%	77.2 to 84.7	82.4	73.0 to 88.6	78.7
5	71.1 to 83.7	75.6	67.4 to 76.8	72.8
10	62.0 to 67.6	65.5	62.6 to 67.2	64.5
15	54.0 to 63.1	58.4	50.5 to 64.4	58.6
20	49.8 to 58.4	52.8	47.9 to 60.6	53.7
	Tests Made at −300° F.			
0%	76.8 to 81.0	79.7	44.9 to 65.7	60.0
5	64.8 to 71.7	68.4	37.9 to 56.3	47.6
10	59.0 to 65.5	62.1	28.6 to 40.1	34.8
15	53.3 to 58.3	55.9	19.8 to 30.3	25.1
20	48.1 to 53.3	51.7	19.6 to 22.9	20.9

*No specimen broke completely.

Table III — Hardness of Cold Worked 18-8

Amount of Reduction	Type 302		Type 304	
	Annealed	Sensitized	Annealed	Sensitized
0%	B-71	B-79	B-81	B-74
5	B-95	B-95	B-91	B-88
10	C-25	C-24	C-24	C-22
15	C-27	C-25	C-26	C-23
20	C-29	C-27	C-26	C-25

microstructures at the approximate center of the 0.562-in. diameter bar.* Fig. 3 gives four representative views. Type 302 without cold work (microstructure not shown) appears quite similar to the micros after 5% cold work, either in annealed or sensitized condition, except that few if any of the grains as annealed etch any more darkly than the average tone. Striations in the grain (incipient in the 5% reduced metal) develop regularly with degree of cold work, as does the precipitation of carbides at the grain boundaries is shown at high magnification in Fig. 4 for both types of alloys cold drawn 20%.

A photomicrograph comparing the metal at the boundary layer of a full penetration weld in Type 302 stainless steel is presented in Fig. 5, p. 704 (weld at extreme bottom). Precipitated carbides resulting from welding in Type 302 do not exist in the weld in Type 304 following similar treatment.

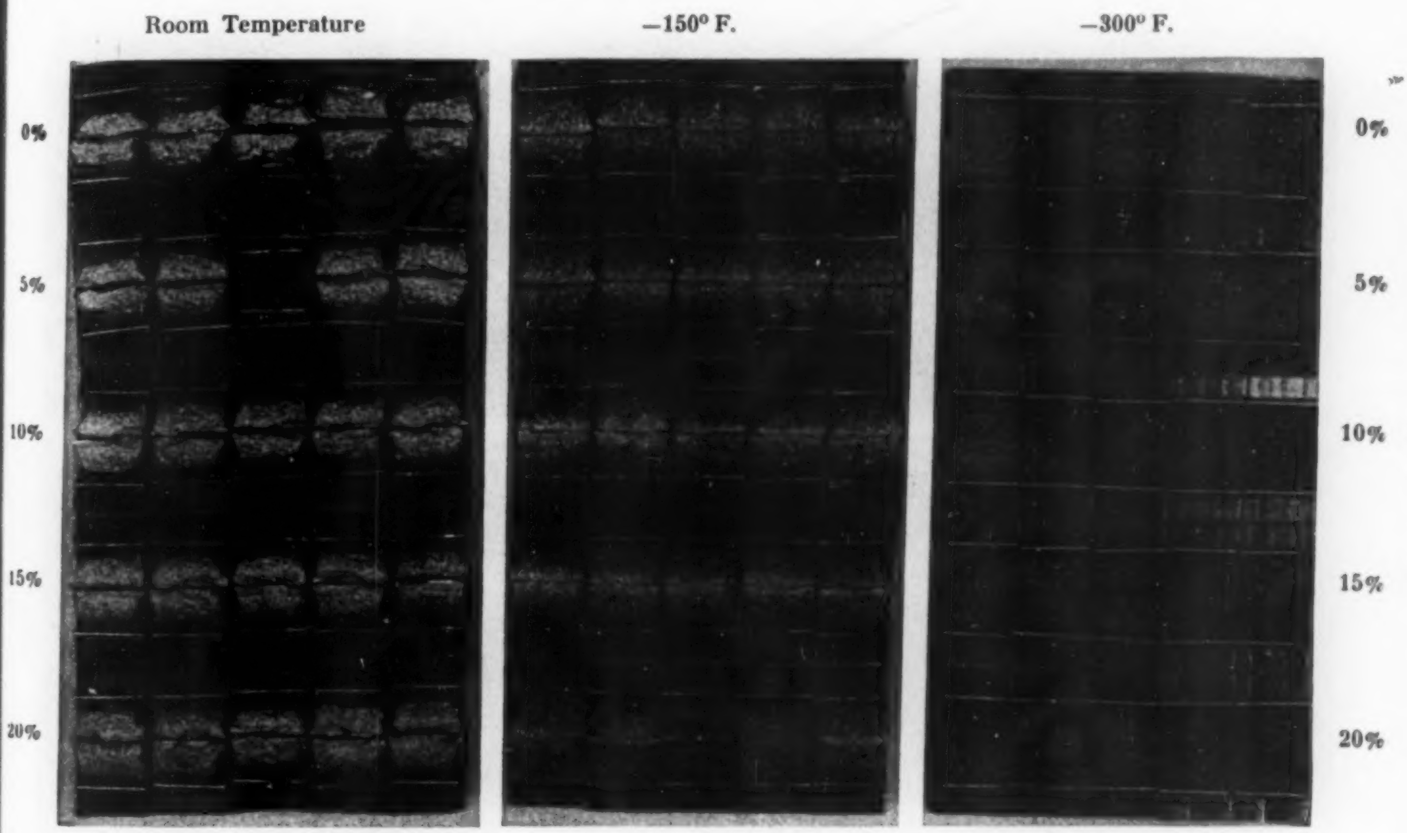


Fig. 2 — Impact Test Bar Fractures for Type 302 in the Sensitized Condition. (Full size)

average grain size in the heat treated specimens. Grain and boundary structures in cold worked Type 302 are shown in more detail at high magnification in Fig. 4.

The grain size is similar for both Type 302 and Type 304 when annealed at 2050° F. Grains coarsen considerably on heating to 2250° F. before the sensitization treatment, but again the grain size of the two alloys is similar. The effect of increasing amounts of cold work is similar for both alloys, regardless of heat treatment. The

Discussion of Test Data

The hardness, both as annealed and as sensitized, has increased with increasing amounts of cold work for both alloy types in similar degree. A decided drop in rate of hardening occurs at 10% cold work; between 10 and 20% cold work the hardness increases only 2 to 4 points on the Rockwell C-scale. Generally, the higher carbon content of Type 302 stainless steel is reflected in increased hardness values over the Type 304 in both annealed and sensitized conditions.

Notch impact tests at room temperature show decreasing ductility with increased cold work. The rates of change are similar for both alloys.

*Editor's Note — A series of micros of utmost excellence accompanied the original manuscript. Unfortunately space permits reproduction of only a few of them.

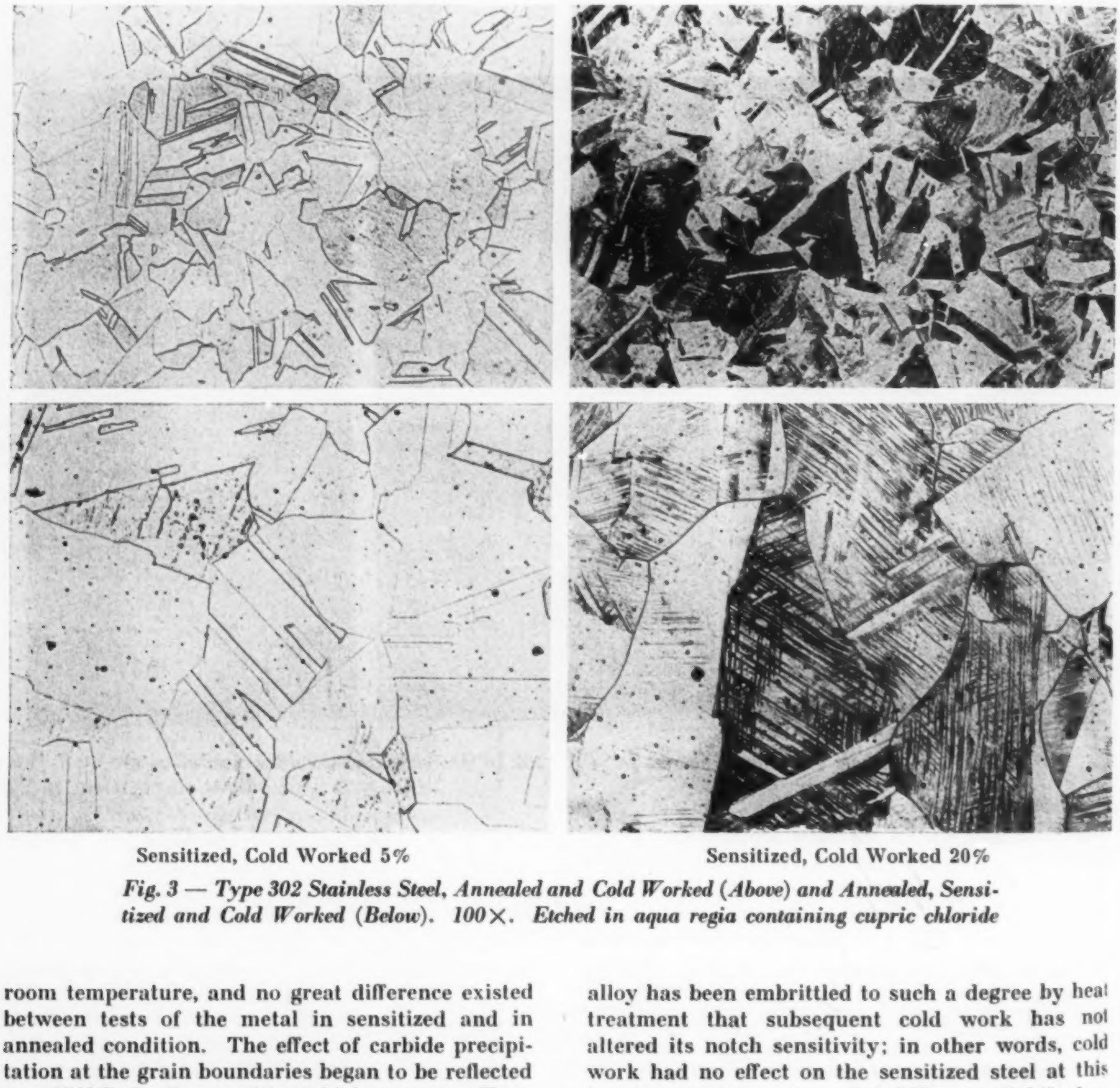
The sensitized alloys exhibit slightly higher average values than those annealed, but this variation did not exceed 5 ft-lb. at any time. Generally, 20% cold work resulted in approximately 50% lower energy absorption values in the room temperature tests.

When tested at −150° F., Type 304 showed slightly higher impact values than obtained at room temperature, and no great difference existed between tests of the metal in sensitized and in annealed condition. The effect of carbide precipitation at the grain boundaries began to be reflected at −150° F. in the sensitized higher carbon Type 302; impact values were about half as high as at room temperature. Annealed Type 302 is about as tough at −150° F. as at room temperature. However, annealed values for Type 302 are between 6 and 9 ft-lb. below figures for Type 304 alloy at this temperature.

The spread between the high- and low-carbon 18-8 steels becomes more apparent (as well as the effect of increased grain size) when these alloys are notch tested at −300° F. It is interesting to note from the data in Tables I and II that Type 302 sensitized has dropped to about 10 ft-lb. The alloy has been embrittled to such a degree by heat treatment that subsequent cold work has not altered its notch sensitivity; in other words, cold work had no effect on the sensitized steel at this low temperature. Annealed 302 was slightly less tough at −300° F. than when tested at −150° F.

Impact values for annealed Type 304 at −300° F. were but slightly below those occurring at −150° F. The effect of grain coarsening, com-

Annealed, Cold Worked 5% | Annealed, Cold Worked 20%



Sensitized, Cold Worked 5% | Sensitized, Cold Worked 20%

Fig. 3 — Type 302 Stainless Steel, Annealed and Cold Worked (Above) and Annealed, Sensitized and Cold Worked (Below). 100×. Etched in aqua regia containing cupric chloride

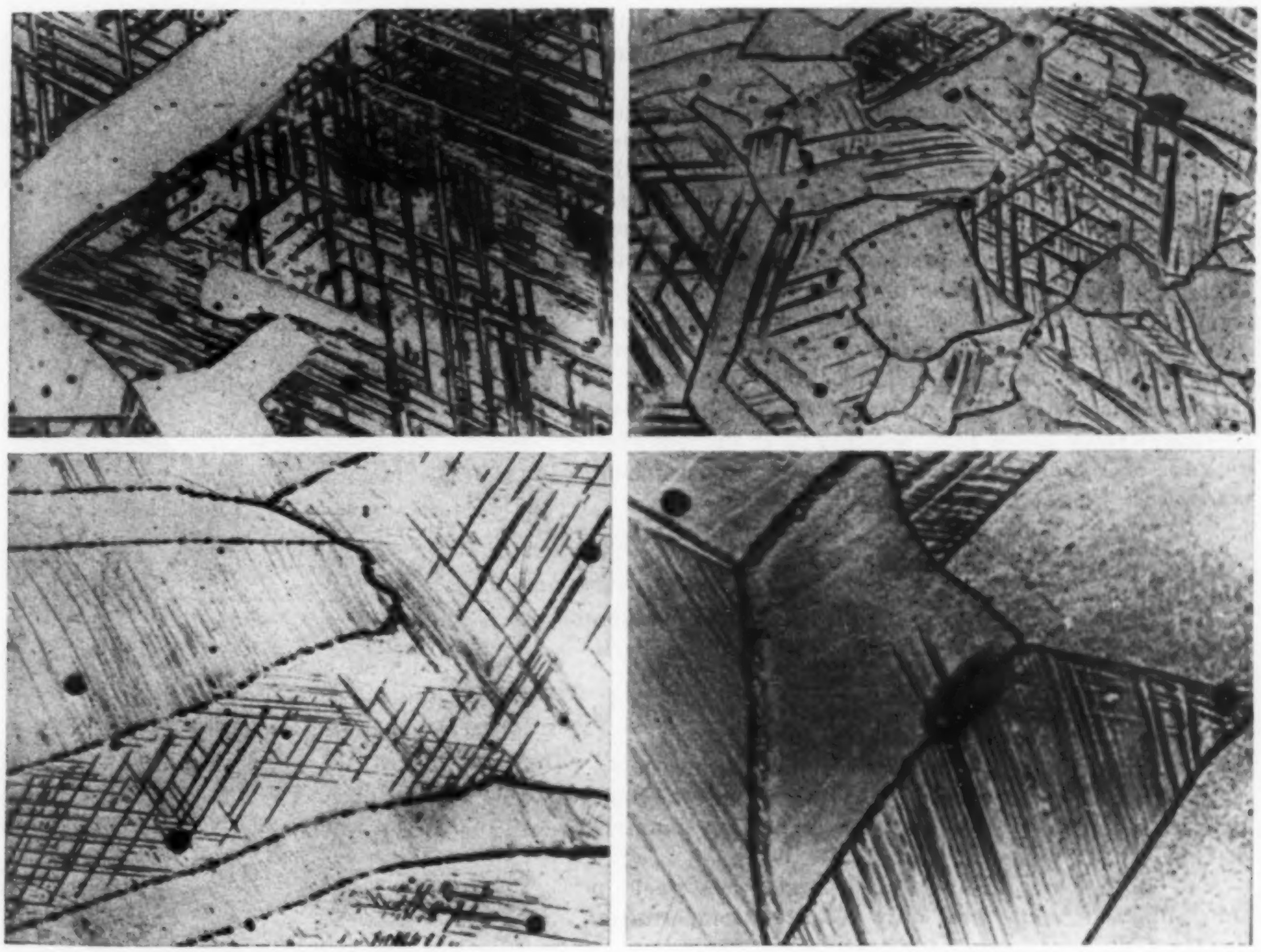
bined with moderate carbide precipitation, on the notch toughness of this alloy is shown in the figures for sensitized steel. Impact strengths were lowered from 60 ft-lb. with no cold work to 20 ft-lb. after 20% cold work — about 25 ft-lb. (on the average) lower than the figures for annealed and cold worked bars, not sensitized.

Examination of the broken test bars reveals

showed increasing embrittlement and crystallinity with increased cold work at −300° F.

During the preliminary annealing the alloys were heated to a high temperature to dissolve completely those elements capable of forming separate crystallites on cooling. When this solid solution is quenched, it is retained in a state of supersaturation. Subsequent reheating to a tem-

Type 302 Annealed　　　　Type 304 Annealed



Type 302 Sensitized　　　　Type 304 Sensitized

Fig. 4 — Views at High Magnification of Grains and Grain Boundary Conditions of 18-8 After 20% Cold Work. 750× except lower right, which is 2500×

fibrous ductile fractures in both alloys at all temperatures when tested in the annealed state, or at room temperature in the sensitized condition. At −150° F. both alloys exhibit moderate crystalline fractures with decreasing ductility as the amount of cold work increases; however, Type 302 shows this to a greater degree (Fig. 2). Brittle crystalline fractures were obtained in all tests at −300° F. of sensitized Type 302. Type 304, sensitized,

perature in the 900 to 1400° F. range causes the dissolved carbon to migrate to the grain boundaries at a more rapid rate than the chromium, leaving the immediately adjacent metal greatly depleted in chromium as the carbon takes it out of solution there and forms carbides. The deposition of brittle carbides at the grain boundaries tends to envelop the normally tough austenite with a honeycomb of brittle carbides. This

embrittlement becomes very serious when the grain size becomes large and sufficient carbon is present.

Types 302 and 304, in the annealed condition, reflect in their high energy values the uniform dispersion of chromium and of carbon throughout each grain. Increased hardness resulting from cold deformation has increased the brittleness at all temperatures of testing.

When analyzing the test data of these alloys in the sensitized state, it is felt that Type 302 stainless steel reveals principally the relationship between carbide precipitation and energy absorption at low temperatures, while figures for Type 304 stainless steel are primarily indicative of the relationship between grain size and energy absorption.

The above findings may be translated into actual low-temperature service conditions when the welded specimens are considered. Microexamination of the weld area reveals moderate grain coarsening in the heat affected zones of both alloys. Only the higher carbon Type 302 shows carbide precipitation at grain boundaries. This embrittled condition will result in increasingly lower ductility as the temperature is decreased. Bending stresses will impose cold work upon weld areas. From the data obtained in this investigation it is reasonable to assume that energy absorption values will be considerably lower than anticipated if the designer depends on the annealed low-temperature impact characteristics of these austenitic stainless steels.

Conclusions

1. Grain coarsening through heat treatment results in lowered notch impact values at subatmospheric temperatures.

2. The degree of sensitization is proportional to the carbon content in the austenitic 18-8 alloys.

3. Cold deformation increases the hardness.

4. Ductility, as measured by the Charpy keyhole notch impact test, decreases with increasing amounts of cold work.

5. Both Type 302 and Type 304 stainless steels in the annealed state are only slightly temperature-sensitive.

6. Type 304 stainless steel in the sensitized condition is stable, as far as energy absorption values are concerned, down to −150° F.; at −300° F. impact values dropped 20 to 30 ft-lb.

7. Sensitized Type 302 stainless steel shows increasing embrittlement with decreasing temperatures.

8. At −300° F. the notch toughness of sensitized Type 302 is not affected by cold work.

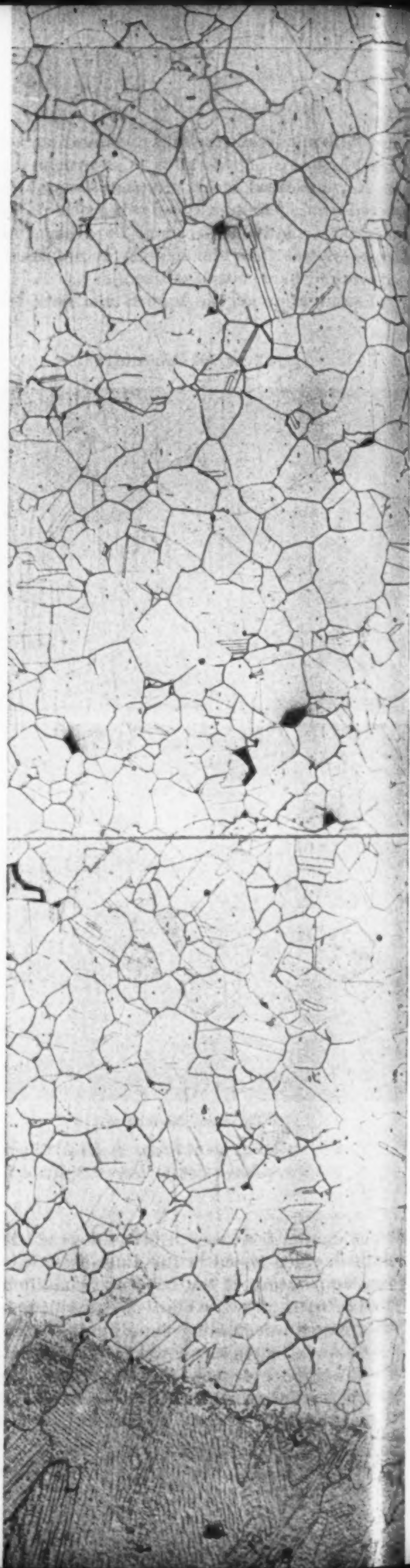
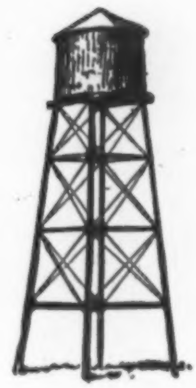


Fig. 5 — Composite Photomicrograph at 100× of As-Welded Bar of Type 302, Previously Annealed at 2050° F. Note accentuated boundaries (carbide precipitation) throughout all the plate material shown, as well as in the coarse dendrites of the weld

HOW MUCH PRESSURE IS PUT

on SCRAP-COLLECTIONS in your plant?



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Take a good look around your plant . . . comb your entire property for broken, worn-out or obsolete machines . . . discarded line shafting . . . unusable girders . . . old chain . . . every sort of scrap metal.

Consult your local scrap dealer for advice on types, grades and sizes.

The amount of steel available depends upon the tonnage of scrap turned in. Everyone is affected by the scrap situation, and now is the time for each individual to get every available pound of scrap back to the mills.

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Typical Data for Magnetic Materials

High-Permeability Materials

Material	Form	Approximate Per Cent Composition: Fe	Ni	Co	Mo	Other	Typical Heat Treatment (°C.)	Permeability at B = 20 Gausses	Maximum Permeability	Saturation Flux Density B, Gausses‡	Hysteresis‡ Loss, W_h Ergs per Cu.Cm.	Coercive‡ Force H_c Oersteds	Resistivity, Microhm-Cm.	Density, G. per Cu.Cm.
Cold rolled steel	Sheet	98.5	—	—	—	—	950 Anneal	180	2,000	21,000	—	1.8	10	7.88
Iron	Sheet	99.91	—	—	—	—	950 Anneal	200	5,000	21,500	5,000	1.0	10	7.88
Purified iron	Sheet	99.95	—	—	—	—	1480 H_2 + 880	5,000	180,000	21,500	300	0.05	10	7.88
4% Silicon-iron	Sheet	96	—	—	—	4 Si	800 Anneal	500	7,000	19,700	3,500	0.5	60	7.65
Grain oriented*	Sheet	97	—	—	—	3 Si	800 Anneal	1,500	30,000	20,000	—	0.15	47	7.67
45 Permalloy	Sheet	54.7	45	—	—	0.3 Mn	1050 Anneal	2,500	25,000	16,000	1,200	0.3	45	8.17
45 Permalloy†	Sheet	54.7	45	—	—	0.3 Mn	1200 H_2 Anneal	4,000	50,000	16,000	—	0.07	45	8.17
Hipernik	Sheet	50	50	—	—	—	1200 H_2 Anneal	4,500	70,000	16,000	220	0.05	50	8.25
Monimax	Sheet	—	—	—	—	—	1125 H_2 Anneal	2,000	35,000	15,000	—	0.1	80	8.27
Sinimax	Sheet	—	—	—	—	—	1125 H_2 Anneal	3,000	35,000	11,000	—	—	90	—
78 Permalloy	Sheet	21.2	78.5	—	—	0.3 Mn	1050 + 600 Q**	8,000	100,000	10,700	200	0.05	16	8.60
4-79 Permalloy	Sheet	16.7	79	—	4	0.3 Mn	1100 + Q	20,000	100,000	8,700	200	0.05	55	8.72
Mu metal	Sheet	18	75	—	—	2 Cr, 5 Cu	1175 H_2	20,000	100,000	6,500	—	0.05	62	8.58
Supermalloy	Sheet	15.7	79	—	5	0.3 Mn	1300 H_2 + Q	100,000	800,000	8,000	—	0.002	60	8.77
Permendur	Sheet	49.7	—	50	—	0.3 Mn	800 Anneal	800	5,000	24,500	12,000	2.0	7	8.3
2V Permendur	Sheet	49	—	49	—	2 V	800 Anneal	800	4,500	24,000	6,000	2.0	26	8.2
Hiperco	Sheet	64	—	34	—	Cr	850 Anneal	650	10,000	24,200	—	1.0	25	8.0
2-81 Permalloy	Insulated powder	17	81	—	2	—	650 Anneal	125	130	8,000	—	<1.0	10^6	7.8
Carbonyl iron	Insulated powder	99.9	—	—	—	—	— —	55	132	—	—	—	—	7.86
Ferroxcube III	Sintered powder		$MnFe_2O_4 + ZnFe_2O_4$				— —	1,000	1,500	2,500	—	0.1	10^8	5.0

*Properties in direction of rolling. †Similar properties for Nicaloi, 4750 alloy, Carpenter 49, Armco 48. ‡At saturation. **Q Quench or controlled cooling.

Permanent Magnet Alloys

Material	Per Cent Composition (Remainder Fe)	Heat Treatment* (Temperature, °C.)	Magnetizing Force $H_{max.}$ Oersteds	Coercive Force H_c Oersteds	Residual Induction B_r Gausses	Energy Product $BH_{max.}$ $\times 10^{-6}$	Method of Fabrication†	Mechanical Properties‡	Weight, Lb. per Cu. In.
Carbon steel	1 Mn, 0.9 C	Q 800	300	50	10,000	0.20	HR, M, P	H, S	0.280
Tungsten steel	5 W, 0.3 Mn, 0.7 C	Q 850	300	70	10,300	0.32	HR, M, P	H, S	0.292
Chromium steel	3.5 Cr, 0.9 C, 0.3 Mn	Q 830	300	65	9,700	0.30	HR, M, P	H, S	0.280
17% Cobalt steel	17 Co, 0.75 C, 2.5 Cr, 8 W	—	1,000	150	9,500	0.65	HR, M, P	H, S	—
36% Cobalt steel	36 Co, 0.7 C, 4 Cr, 5 W	Q 950	1,000	240	9,500	0.97	HR, M, P	H, S	0.296
Remalloy or Comol	17 Mo, 12 Co	Q 1200, B 700	1,000	250	10,500	1.1	HR, M, P	H	0.295
Indalloy (sintered)	— Mo, — Co	— —	1,000	240	9,000	0.9	HR, M, P	H	0.290
Alnico I	12 Al, 20 Ni, 5 Co	A 1200, B 700	2,000	440	7,200	1.4	C, G	H, B	0.249
Alnico II	10 Al, 17 Ni, 2.5 Co, 6 Cu	A 1200, B 600	2,000	550	7,200	1.6	C, G	H, B	0.256
Alnico II (sintered)	10 Al, 17 Ni, 2.5 Co, 6 Cu	A 1300	2,000	520	6,900	1.4	Sn, G	H	0.249
Alnico IV	12 Al, 28 Ni, 5 Co	Q 1200, B 650	3,000	700	5,500	1.3	Sn, C, G	H	0.253
Alnico V	8 Al, 14 Ni, 24 Co, 3 Cu	AF 1300, B 600	2,000	550	12,500	4.5	C, G	H, B	0.264
Alnico VI	8 Al, 15 Ni, 24 Co, 3 Cu, 1 Ti	— —	3,000	750	10,000	3.5	C, G	H, B	0.268
Alnico XII	6 Al, 18 Ni, 35 Co, 8 Ti	— —	3,000	950	5,800	1.5	C, G	H, B	0.26
Vicalloy I	52 Co, 10 V	B 600	1,000	300	8,800	1.0	C, CR, M, P	D	0.295
Vicalloy II (wire)	52 Co, 14 V	CW + B 600	2,000	510	10,000	3.5	C, CR, M, P	D	0.292
Cunife (wire)	60 Cu, 20 Ni	CW + B 600	2,400	550	5,400	1.5	C, CR, M, P	D, M	0.311
Cunico	50 Cu, 21 Ni, 29 Co	— —	3,200	660	3,400	0.80	C, CR, M, P	D, M	0.300
Vectolite	30 Fe_2O_3, 40 Fe_3O_4	— —	3,000	1,000	1,600	0.60	Sn, G	W	0.113
Silmanal	86.8 Ag, 8.8 Mn, 4.4 Al	— —	20,000	6,000[1]	550	0.075	C, CR, M, P	D, M	0.325
Platinum-cobalt	77 Pt, 23 Co	Q 1200, B 650	—	2,600	4,500	3.8	C, CR, M	D	—
Hyflux	Fine powder	— —	2,000	390	6,600	0.97	—	—	0.176

[1] Value given is intrinsic H_c.
*Q – Quenched in oil or water. A – Air cooled. B – Baked. F – Cooled in magnetic field. CW – Cold worked.
†HR – Hot rolled or forged. CR – Cold rolled or drawn. M – Machined. G – Must be ground. P – Punched. C – Cast. Sn – Sintered.
‡H – Hard. B – Brittle. S – Strong. D – Ductile. M – Malleable. W – Weak.

Compiled by R. A. Chegwidden

A Review of Magnetic Materials Especially for Communication Systems

By R. A. Chegwidden
Magnetics Research Dept.
Bell Telephone Laboratories
Murray Hill, N. J.

Both the high-permeability materials and the alloys used for permanent magnets are included in this review. The author has also compiled a data sheet (printed on page 704-B of this issue) which summarizes the typical properties of all the materials discussed in this article.

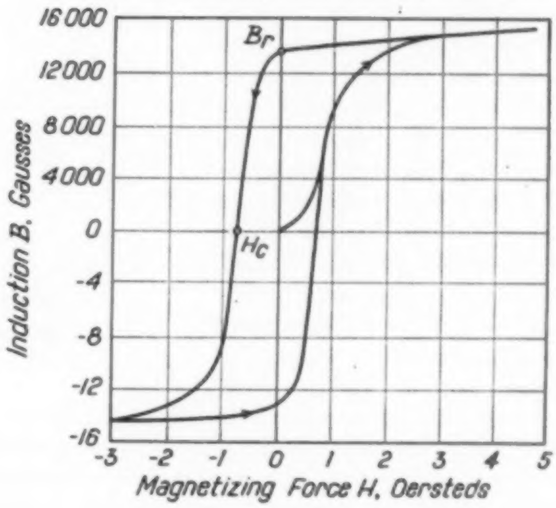
IN COMPARISON with the huge tonnages of structural steel and nonferrous metals produced in this country, the output of magnetic materials is small. Their importance can hardly be overemphasized, however, when it is realized that almost all electrical apparatus depends on them in some manner for power and performance.

In this discussion of magnetic materials, an attempt will be made to describe the present state of the art in this country, with particular emphasis on materials used in communication systems. The properties of a number of these materials will be given and some of the developments in magnetic theory will be mentioned.

It is customary to divide magnetic materials into two groups — the strongly magnetic, or ferromagnetic materials, and the weakly magnetic, or paramagnetic and diamagnetic materials. Since the latter have only specialized uses, this discussion will be limited to ferromagnetic materials.

Magnetization Curve and Hysteresis Loop — If a ring sample of a ferromagnetic material is wound with two copper wire windings, a primary and a secondary, and a magnetizing force is created by means of an electric current in the primary, the magnetic flux density, as measured by a fluxmeter connected to the secondary, will be found to be hundreds, perhaps thousands of times that produced were the magnetic material not there. The ratio of the flux density, B, to the magnetizing force, H, is a measure of the permeability, μ, of the material. If a plot is made of B as H is increased, we obtain the familiar magnetization curve (Fig. 1) which finally reaches a maximum or saturation point characteristic of the material under test. If now the plot is continued as H is reduced to zero, increased to a maximum in the negative direction and continued back to a maximum in the positive direction, we obtain the characteristic hysteresis loop for the sample. The

Fig. 1 — Typical Magnetization Curve and Hysteresis Loop for Iron



area enclosed within the loop indicates the energy lost in the process; the point at which the loop crosses the ordinate indicates the residual induction, B_r, which is the flux density retained in a closed magnetic circuit after magnetization; and the point at which the loop crosses the abscissa indicates the coercive force, H_c, the measure of the material's ability to resist demagnetization after magnetizing. The magnetization curves and hysteresis loops plus the electrical resistivity give most of the essential information for evaluating magnetic materials. High resistivity is desirable for alternating-current applications to keep eddy-current losses at a minimum.

Present Theory — Of all the elements only iron, nickel and cobalt are strongly ferromagnetic. Although this has been known for many years, it is only within recent years that a satisfactory theory has been developed to explain the phenomena.

Present theory, ably described by Bozorth,[1] ascribes the property of ferromagnetism to the spinning electrons within an incomplete inner electron shell of the atom and to the spacing of the atoms. The electrons, spinning in clockwise and counterclockwise directions, act as tiny magnets and in many atoms the spins neutralize one another so that no excess spin remains to produce manifestations of magnetism. In iron, cobalt and nickel, however, there is an excess of electrons spinning in one direction and the spacing of the atoms is such that the effects can add up to produce a high degree of ferromagnetism. The electron shells in the iron atom can be pictured as in Fig. 2. A few other elements such as manganese and chromium also have incomplete inner electron shells but the normal spacing of the atoms does not fulfill the conditions necessary to produce ferromagnetism. A favorable spacing of the atoms in alloys such as the Heusler alloys, composed of manganese, copper and aluminum, is believed to account for their ferromagnetic behavior.

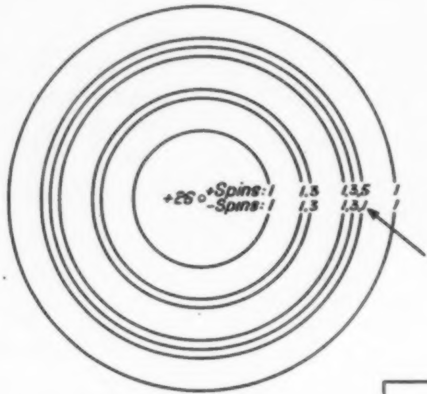


Fig. 2 (Above) — Electron Shells in the Iron Atom

The magnetization curve and hysteresis loop are explained in terms of the domain theory of magnetism which states that the fields from groups of atoms align themselves, even in the unmagnetized state, in small volumes called domains. Within a domain the fields from the spinning electrons are all in alignment and thus at the saturation point — magnetically saturated, that is to say. In an unmagnetized piece of iron, for example, the fields of the domains are in random directions but their vector sum is zero.

When a magnetic field is applied, magnetism progresses as a boundary displacement which results in an enlargement of those domains in line with the applied field at the expense of their less favored neighbors; as the field is increased, more and more domains are brought in line until at high fields practically all the domains are finally forced to align themselves in the direction of the applied field and the material reaches magnetic saturation (Fig. 3).

Evidence of the existence of domains was first deduced from the Barkhausen effect (insert of Fig. 3), which shows that magnetization progresses in small definite steps. Conclusive evidence is had when finely divided ferromagnetic compounds settle on the surfaces of unmagnetized and magnetized samples[2] (Fig. 4). To exhibit high permeability, the domains must be free to align themselves easily in the direction of an applied field. Proper heat treatment to produce strain-free conditions is thus essential (Fig. 5).

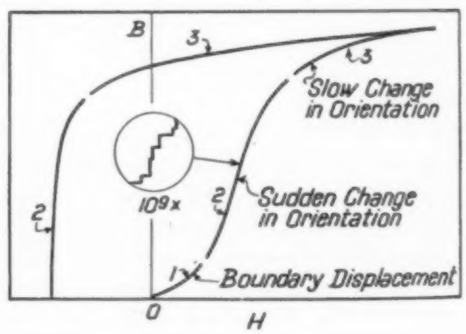


Fig. 3 — The Three Kinds of Changes in Magnetization. Insert shows small steps characteristic of Barkhausen effect

High-Permeability Materials

Until the twentieth century, unalloyed iron was the only high-permeability material of importance. Even today, because of its low cost, iron is used in great quantities for magnetic purposes. It is usually made by the openhearth process, hot rolled to a convenient size for cold rolling, then cold rolled to the desired thickness. It is used in telephone relays, switches, coin collectors and all sorts of direct-current apparatus. Although commercial iron made for magnetic purposes contains only very small amounts of impurities, their deleterious effect is such that eventually large

[1]Literature references will be found on p. 714.

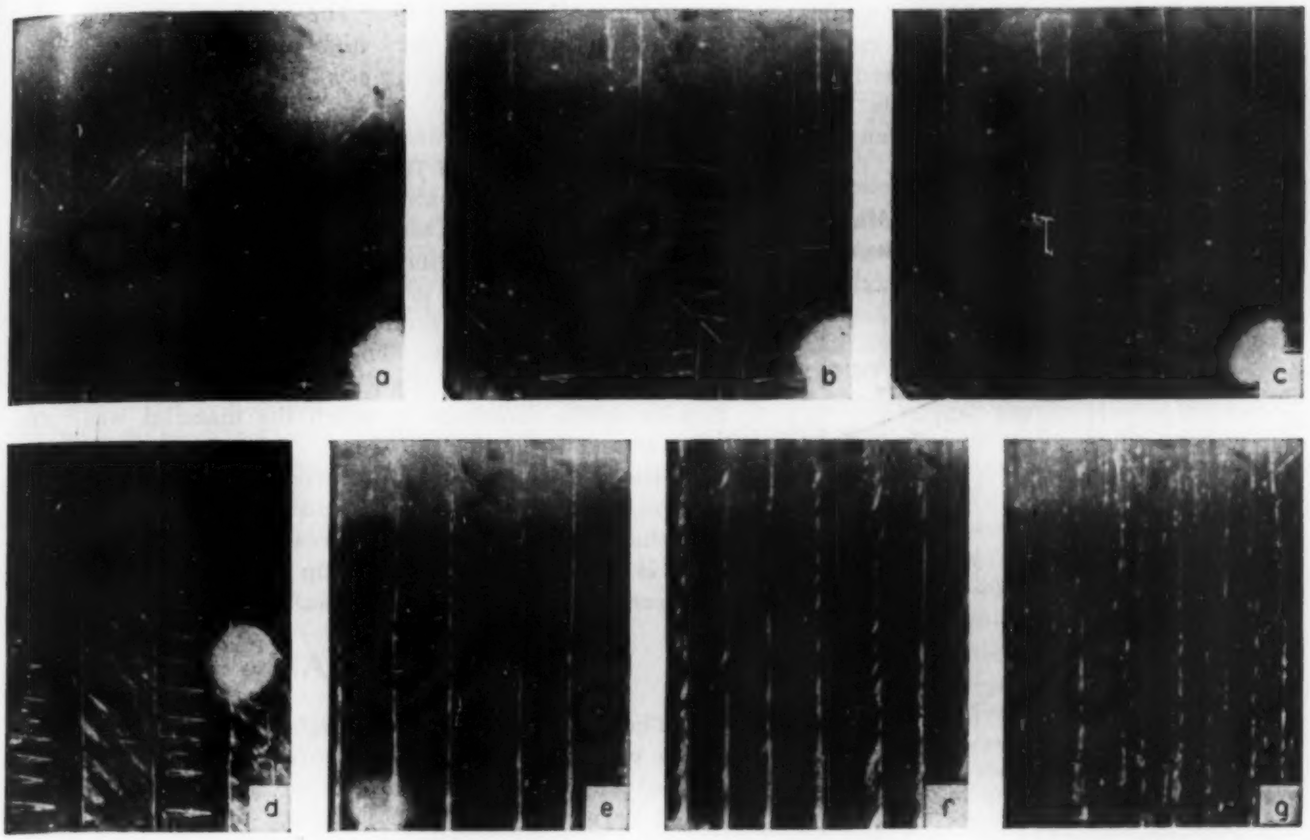


Fig. 4 — Powder Patterns on Silicon-Iron Crystal as it Changes From Unmagnetized State (a) Through (b), (c), (d), (e) and (f) to the Saturated State (g)

reductions in the initial magnetic quality occur, as time goes on, in iron subjected to the operating temperatures common to many types of electrical devices. Even at room temperature, this aging effect is apparent.

The work of Cioffi[3] at the Bell Laboratories and Yensen[4] of Westinghouse has shown that remarkable improvements can be obtained in the magnetic quality of iron if certain nonmetallic impurities are reduced to very low levels (Fig. 6 and 7). These results were produced by heat treatments for long periods of time at temperatures near the melting point in pure, dry hydrogen or in a vacuum. High-purity iron of this type

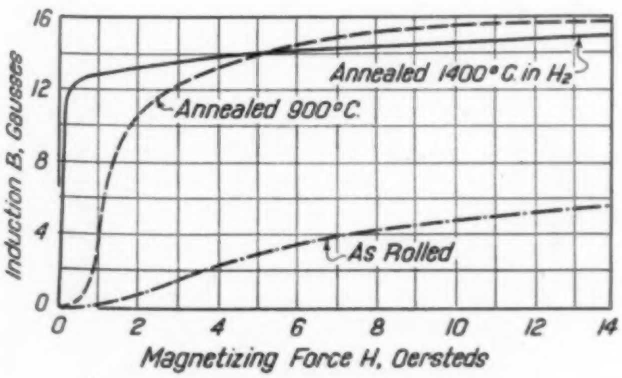


Fig. 5 — Effect of Heat Treatment on the Magnetization Curve for Iron (Cioffi)

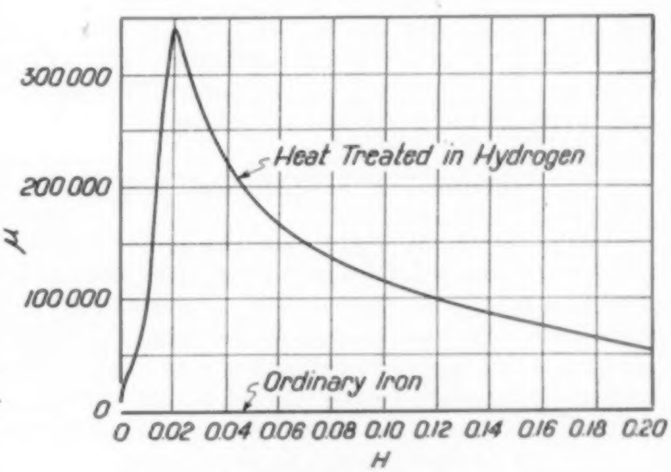


Fig. 6 — Permeability Curves of Ordinary Iron and of Iron Purified by Heat Treatment in Hydrogen at 1500° C. (Cioffi)

not only has excellent magnetic quality but is nonaging as well. Typical compositions of such material, as compared with Armco iron, are shown in Table I, in which it is indicated that even tiny

Fig. 7 — Effect of Carbon on the Maximum Permeability of Iron (Yensen)

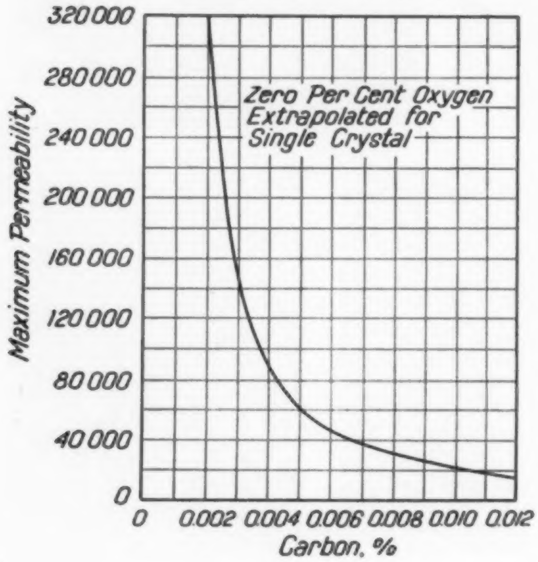


Table I — Compositions of High-Purity Irons

Material	C	S	Mn	P	Si	O	N	$\mu_{max.}$
Armco iron	0.012	0.018	0.030	0.004	0.002	0.030	0.0018	7,000
After 3 hr. at 1475° C. in dry H_2	0.005	0.006	0.028	0.004	—	0.003	0.0003	30,000
After 18 hr. at 1475° C. in dry H_2	0.005	<0.003	0.028	0.004	—	0.003	0.0001	227,000

amounts of interstitial elements like carbon, nitrogen, sulphur, and oxygen can cause strains in the crystal lattice that adversely affect magnetic quality. This high-quality iron has not found widespread use in American industry as yet, however, because of the cost of the purification treatment.

Silicon-Iron, or "Electrical Steel Sheet"

At the beginning of the twentieth century, Hadfield of England introduced the first important alloy of high-purity iron, namely silicon-iron. Silicon-iron, containing up to about 4% silicon, is low in cost, practically nonaging and has lower losses and, for many purposes, better magnetic quality than iron. Its higher electrical resistivity makes it suitable for alternating-current machinery where it is used in great quantities.

A study of the magnetic properties of single crystals has shown that the properties along a certain preferred direction may be many times better than along other directions. The work of Williams,[2] for example, indicates that very high magnetic quality can be obtained in pure silicon-iron crystals, along the (100) crystal plane (Fig. 8 and 9).

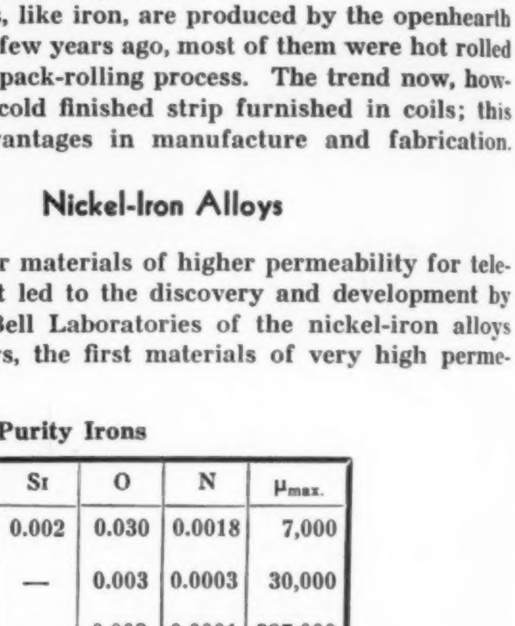


Fig. 8 — Permeability of a Single Crystal of Silicon-Iron

A commercial method for producing a high degree of preferred orientation of the silicon-iron crystals in a polycrystalline sheet was patented by Goss of the Cold Metal Process Co. in 1933. This process, a combination of heat treatment and cold rolling, has been developed further by several companies, and grain oriented silicon-irons of high quality are now being produced. One of these is perhaps better known as Hipersil. The properties of grain oriented materials are usually outstanding only when the magnetization is in the direction in which the material was rolled (Fig. 10 and Table II on p. 710).

Silicon-irons, like iron, are produced by the openhearth process. Until a few years ago, most of them were hot rolled into sheets by a pack-rolling process. The trend now, however, is toward cold finished strip furnished in coils; this has certain advantages in manufacture and fabrication.

Nickel-Iron Alloys

The need for materials of higher permeability for telephone equipment led to the discovery and development by Elmen[5] at the Bell Laboratories of the nickel-iron alloys called Permalloys, the first materials of very high perme-

ability. One of the first of these alloys, 78 Permalloy, was developed for loading submarine cable and for sensitive telephone and telegraph relays. Its magnetization curve, in comparison with that of Armco iron, is shown in Fig. 11.

The high permeability of the Permalloys can be accounted for in part by the fact that they have a low anisotropy constant K, which is a function of the difference between the magnetization curves in the (100) and (110) directions of a single crystal. The constant is positive for iron, negative for nickel, and practically zero for Permalloys in the range 60 to 70% nickel. When the anisotropy is small, the magnetic domains can respond more easily to magnetic fields.

Also, the magnetostriction effect (the slight change in physical dimensions that occurs when a ferromagnetic body is magnetized) is positive for iron and negative for nickel. The algebraic sum of these forces is approximately zero for the alloy containing 80% Ni and 20% Fe, and it is in this region of low anisotropy and low magnetostriction that we find alloys of very high initial permeability. Although outside this range, 45 Permalloy has excellent over-all properties and has many uses because of its higher saturation and resistivity. It is still the best alloy for many alternating-current devices such as certain types of voice frequency coils, relays, and receivers.

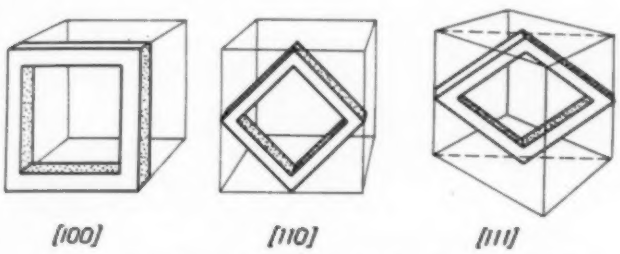


Fig. 9 — Location of Samples in the Crystal of Silicon-Iron Having Permeability as Shown in Fig. 8

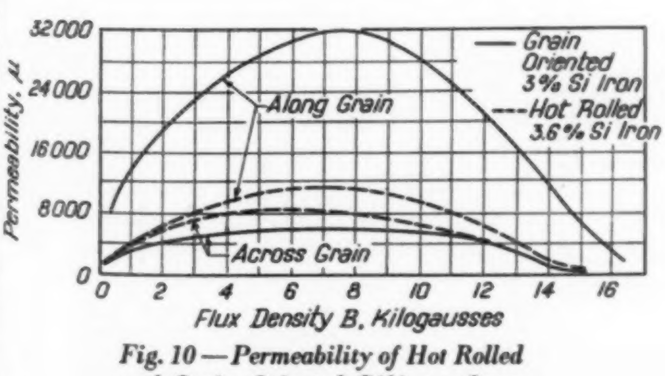


Fig. 10 — Permeability of Hot Rolled and Grain Oriented Silicon-Iron

Nickel-iron alloys in the 45 to 50% nickel class are manufactured as Nicaloi, 4750 alloy, Carpenter 49, Armco 48, and others, and in a high-purity form called Hipernik. The permalloys, because of their high permeability and low losses, have made possible many of the improvements we enjoy in telephone equipment today.

A new development in this same field of alloys is the grain oriented 50% nickel-iron alloy developed for use in certain reactors for mechanical rectifiers in Germany and called Permenorm 5000-Z. This material is characterized by a hysteresis loop that is substantially rectangular. A description of the material and its heat treatment is given in a U. S. Naval Ordnance publication, "Papers Presented at the Naval Ordnance Laboratory Magnetic Materials Symposium", dated June 15, 1948. Permenorm 5000-Z requires 99% cold reduction to develop grain orientation. It is not yet available commercially.

The addition of molybdenum or chromium to the nickel-irons increases the resistivity and produces still more interesting alloys. Examples are 4-79 Molybdenum Permalloy containing 4% Mo and 79% Ni, and Mu Metal, containing 75% Ni, 2% Cr and 5% Cu. Both these materials are capable of initial permeabilities higher than 20,000. This compares with 200 for Armco iron and 5000 for hydrogen-purified iron.

Other variations of the nickel-irons include the high resistivity alloys Monimax and Sinimax. These are modifications of 4750 alloy with molybdenum or silicon.

Supermalloy

Recent development work at the Bell Laboratories on molybdenum permalloy using high-purity techniques has produced a remarkable material called Supermalloy.[1] Supermalloy is capable of initial permeabilities greater than

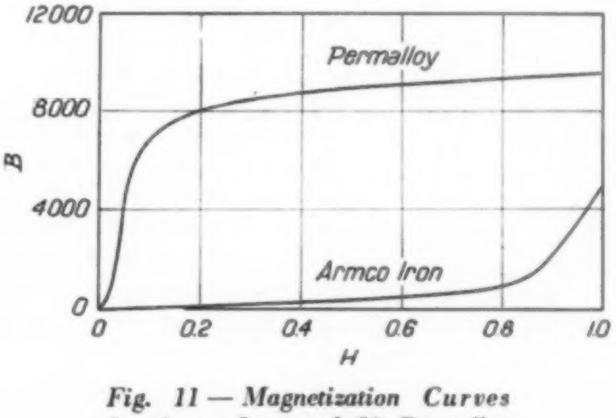


Fig. 11 — Magnetization Curves for Armco Iron and 78 Permalloy

100,000 and maximum permeabilities approaching 1,000,000, by far the highest values reported for polycrystalline materials (Fig. 12). Supermalloy contains about 79% nickel, 5% molybdenum, 15% iron and 0.5% manganese. It is melted in an induction furnace, then hot and cold rolled to size. Parts made of it are finally heat treated at 1300° C. in pure, dry hydrogen and cooled at a controlled rate. Although it is not yet available for general use, tons of this material have been made on a large-scale laboratory basis and it is expected that it will soon be in commercial production.

High initial permeability is of special interest to communication engineers. The progress in the development of materials having high initial permeability is shown in Fig. 13. The "1040 alloy" referred to in the figure is of German origin and contains 72% nickel, 14% copper, 3% molybdenum, the rest iron.

The nickel-iron alloys are unsurpassed for magnetic quality at low and moderate flux densities but their relatively low saturation points make them unsuitable for high-density applications. For high electrical density there are the permendurs, another Bell System development, and Hiperco, produced by Westinghouse. These are alloys of iron and cobalt, and some contain vanadium or chromium.

Because of the high cobalt content, they are expensive and difficult to fabricate but they have the highest permeabilities of any known material at very high flux densities (Fig. 14). Vanadium Permendur can be cold rolled into relatively thin sheet, and it is used in the diaphragm of the modern telephone receiver. It has an important bearing on its high-fidelity performance.

The other permendurs can only be hot rolled or hot forged. As noted above, the addition of about 2% vanadium makes it possible to cold roll the material into thin sheets.

For high-frequency applications or high-stability communication circuits where core losses, particularly eddy-current losses, must be kept extremely low, it has not been found possible to meet design requirements with sheet materials. The problem was solved by using finely divided ferromagnetic powders mixed with suitable non-conducting materials to insulate the powder particles from one another. One of these materials is pure iron powder produced from iron carbonyl and known to the trade as carbonyl iron. Car-

Table II — Some Properties of Samples of Silicon-Irons in 0.014-In. Sheet

Grade	% Si	Power Loss,* Watts/Lb.	D.C. Permeability at 100 Gausses	D.C. Permeability at Max.	D.C. Permeability at 15,000 Gausses	Coercive Force, Oersteds	Resistivity, Microhm-Cm.	Density, G. per Cu.Cm.
Armature	0.5	4.3	—	5,500	800	0.9	19	7.83
Electrical	1.0	3.6	—	6,000	600	0.85	27	7.79
Motor	2.5	2.65	—	5,800	600	0.75	42	7.70
Dynamo	3.2	2.15	1,100	5,800	450	0.65	50	7.65
Transformer	4.5	1.4	2,000	9,000	300	0.3	65	7.57
Grain oriented	3.0							
(Parallel to rolling direction)		1.0	3,000	30,000	7,700	0.15	47	7.67
(Transverse to rolling)		1.4	1,200	10,500	500	0.3	47	7.67

*Power loss = core loss at 60 cycles and at B = 15,000 gausses

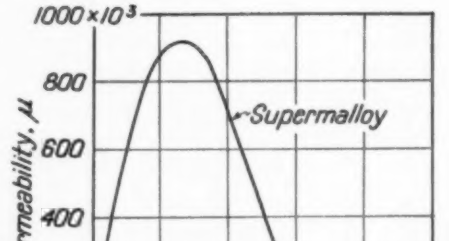


Fig. 12 (Above) — Permeability of Supermalloy and Molybdenum Permalloy

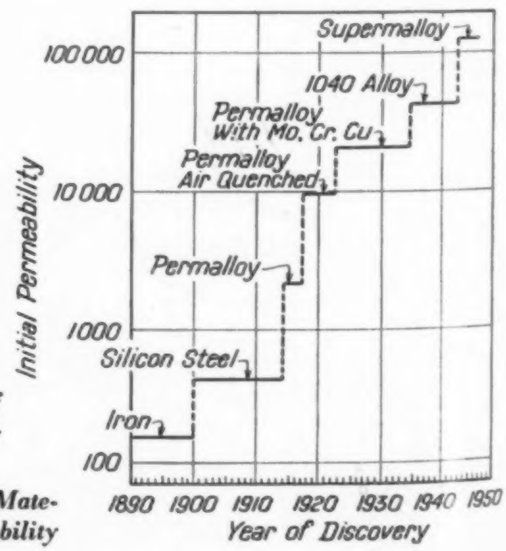


Fig. 13 (Right) — Development of Materials Having High Initial Permeability

bonyl iron cores are frequently used for the tuning components in push-button radio sets. Powdered molybdenum permalloy, another material of this type, is a valuable substance for the manufacture of loading coils for long telephone lines.

For certain types of loading coils where an exceptional stability is required, temperature-compensating alloy powders are added. The permeability of magnetic materials at low flux densities generally increases with temperature up to a certain point and then decreases with temperature, becoming nonmagnetic at a temperature known as the Curie point for the material; at high flux densities the induction decreases with temperature. By developing a high-molybdenum alloy with a low Curie point, it was possible to compensate for changes in permeability with temperature in the standard permalloy powder core.

One of the new and interesting developments in low-loss magnetic materials is the work on ferrites recently reported by the Philips Co. of Holland.[6] By proper selection and by processing complex ferrites to form spinel structures, they have found it possible to obtain materials having low crystal anisotropy and low magnetostriction, resulting in the attainment of high initial permeability accompanied by extremely high resistivity. Initial permeabilities of the order of

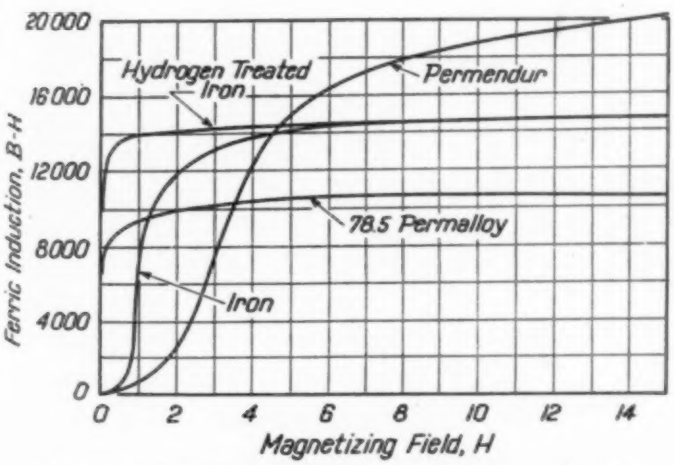


Fig. 14 — Magnetization Curves of Various Materials

1000 accompanied by resistivities of up to 10^6 ohm-cm. have been reported. This value of resistivity compares with 55×10^{-6} ohm-cm. for 4-79 Molybdenum Permalloy. Ferrites, known as "Ferroxcubes", are being made in Holland for use in coils operating at carrier and radio frequencies. The low saturation point, of the order of 2500 gausses, would limit their use to applications involving low flux density.

The ferrites are of the general formula

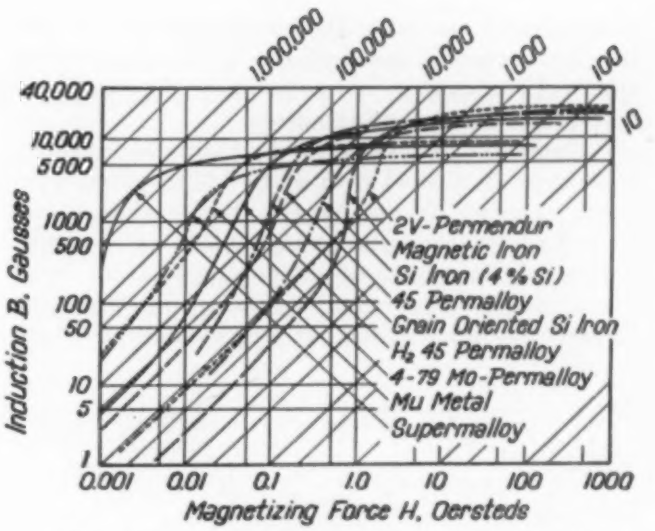


Fig. 15 — Magnetization and Permeability Curves for Various High-Permeability Materials

$MO \cdot Fe_2O_3$ where M denotes a bivalent element. These materials, more like ceramics than metals, are expected to have many applications. The manner in which they are obtained opens a new field for research and may lead to other important developments.

Figure 15 and the data sheet on p. 704-B give comparative properties for a number of high-permeability materials showing the wide range of properties now obtainable.

Permanent Magnet Materials

Permanent magnets are used to produce magnetic fields for many devices such as loudspeakers, meters, magnetos, telephone receivers and many other pieces of common electrical equipment. They are superior to electromagnets for many uses because they maintain their fields without an expenditure of power or heat.

Whereas for high-permeability materials attempts are made to eliminate all sources of strain, in permanent magnet materials high internal strain in the crystal lattice may be desirable.

Permanent magnet materials are evaluated in terms of their coercive force, H_c, residual induction, B_r, and maximum energy product, BH_{max}. This latter term is a measure of the maximum energy that can be obtained from a unit volume of the material. Its value is the maximum product of B and H in the second quadrant of the hysteresis loop, the so-called demagnetization curve for the material.

Most of the important developments in permanent magnets have occurred since about 1930.

Before that time, all of the commercial permanent magnet materials were of the quench hardening type. Like many toolsteels they depended on carbon as the hardening agent.

Prior to World War I, plain high-carbon steels and alloy steel with up to 6% tungsten were used. During World War I, high-carbon steels with 1 to 6% chromium came into use. Coercive forces for this group of alloys ranged from 40 to 70 oersteds. The most significant improvement in the quench hardening alloys came in 1917

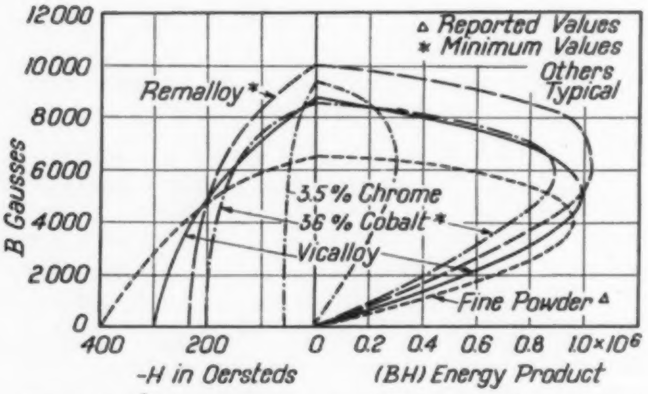


Fig. 16 — Demagnetization and Energy-Product Curves of Materials Having Intermediate Coercive Force

when the Japanese introduced 36% cobalt steel having a coercive force as high as 250. No other advances were made in this field until, in 1931, Seljesator and Rogers[7] of Western Electric Co. reported the results of their application of the principles of dispersion hardening to a series of ternary alloys of iron and cobalt plus molybdenum or tungsten. A complete study of these alloy systems was made by Köster in Germany. The modern permanent magnet alloys, Remalloy, Indalloy and Comol, represent these materials (Fig. 16). These alloys can be hot rolled and are machinable.

Remalloy, Indalloy and Comol

Although the energy product of Remalloy is not much higher than that of 36% cobalt steel (see data sheet on p. 704-B), the material costs less and is essentially stable with time. Remalloy was the forerunner of the whole series of dispersion hardening carbon-free permanent magnet materials from which modern magnets are made. Remalloy magnets are used in most of the present telephone receivers.

Remalloy was followed quickly by the nickel-iron-aluminum Mishima alloys reported by the Japanese. Developments in this same field by the General Electric Co.[8] produced the Alnico alloys, combinations of nickel, iron, aluminum, cobalt and copper. Powerful magnets made of Alnico have changed the conceptions of what can be accomplished with permanent magnets. Alnico magnets have replaced electromagnets in almost all loudspeakers, many types of small motors and generators, and in numerous other devices.

The development of the most powerful of the Alnico type of alloy, known in this country as Alnico V, was based on research work in England and in Holland, where it was found that great improvements could be obtained by heat treating certain of these alloys in a strong magnetic field.

It had been known earlier that high magnetic qualities could be obtained in certain high-permeability materials such as 65 Permalloy[9] by heat treating in a magnetic field, but until Alnico V was developed, no permanent magnet material was known to respond well to this treatment. This process has not been applied commercially to high-permeability materials, partly because the properties at very low flux densities are made poorer, partly because of the cost of the treatment, and also because materials processed in this manner have improved properties only in the direction in which the field is applied; in other directions the properties may be greatly inferior. These limi-

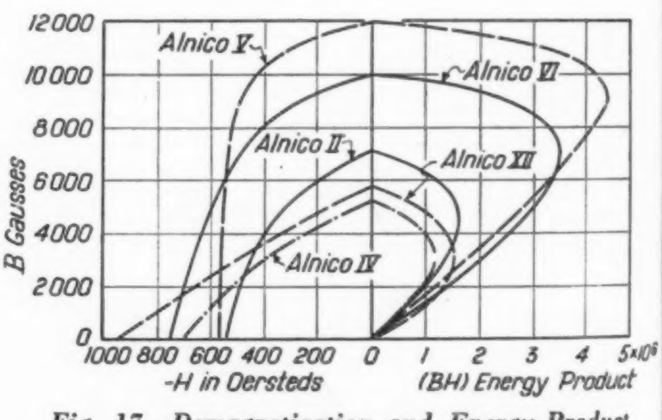


Fig. 17—Demagnetization and Energy-Product Curves of Alnico Alloys Having High Coercive Force

tations apply also to Alnico V, but they are relatively unimportant for permanent magnets in comparison with the advantages gained. Alnico V has an energy product more than four times that of 36% cobalt steel (Fig. 17).

The Alnicos are hard, brittle materials that cannot be worked either hot or cold. Magnets made from them are usually cast and ground to size after heat treating. The heat treatment of the magnets consists of a high-temperature treatment at 1200 to 1300° C., followed by controlled cooling

to about 500° C., then a "bake" for a certain period at 600 to 650° C. to get the optimum properties. For Alnico V and a later variation, Alnico VI, the cooling from the high temperature is accomplished in the presence of a strong magnetic field of 1000 oersteds or more.

Small magnets of Alnico II, Alnico V and Remalloy are now also being produced by powder metallurgy. Such magnets after sintering at high temperatures are mechanically stronger than cast magnets and can be made to have similar magnetic properties after giving them a proper heat treatment. For small and intricately shaped magnets, the lost-wax process of precision casting is sometimes used.

Ductile Magnetic Alloys

It has been customary to think of permanent magnet materials as hard, brittle materials that are difficult if not impossible to cold work. In recent years, however, permanent magnet alloys have been found that can be cold worked readily; in fact, great improvements in properties have been obtained in some of these by drastic cold reductions. Vicalloy,[10] an alloy of vanadium, iron and cobalt, is one of these (Fig. 18). Vicalloy has been found to have superior quality for the magnetic recording of speech. Other alloys of this type are the copper-nickel-iron Cunifes and copper-nickel-iron-cobalt Cunico (Fig. 19).

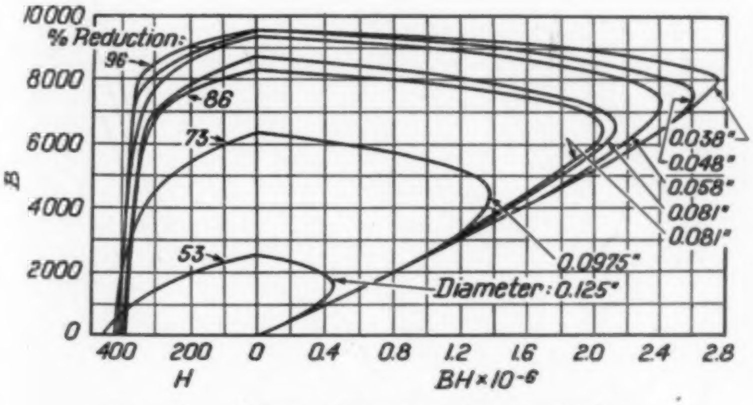


Fig. 18 — Effect of Wire Drawing on Vicalloy (34% Fe, 52% Co, 14% V). After being cold drawn, the wires were "baked" at 600° C.

Within the last ten years, further work with fine iron powders by Dean and Davis[11] and others has disclosed that, if the particle size of a ferromagnetic powder can be made small enough, permanent magnet qualities are obtained (Fig. 16). By proper processing, it has been found possible to obtain metallic powders having intrinsic coercive forces and residual inductions comparable with some of the alnicos. A metallic powder called Hyflux is now being produced in this country as a thin coating on a paper tape for use in the recording of sound.

The iron oxide magnetite, the earliest known magnet, has been combined with other iron oxides and cobalt oxides to form an interesting type of permanent magnet. These materials are nonmetallic and, although their energy products are not very high by present standards, they have high coercive forces and are of light weight. One of these, called Vectolite, is used in airplane instruments where light weight is essential.

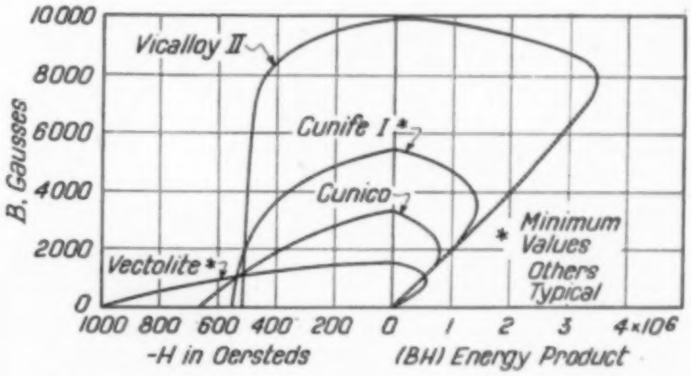


Fig. 19 — Demagnetization and Energy-Product Curves of Several Materials Having High Coercive Force

Even the precious metals have been found capable of forming permanent magnet materials. One of these, an alloy of silver, manganese and aluminum, called Silmanal in this country, has an extremely high intrinsic coercive force, 6000 oersteds, although its residual induction is very small. Another of these alloys is composed of platinum and cobalt. Both of these can be cold worked. The data sheet on p. 704-B gives properties for a number of permanent magnet materials.

There seems to be no limit to the number of alloys that can be made to exhibit ferromagnetic properties. The future for magnetic materials is bright and in the years to come we can expect materials having even lower losses, and better permeabilities at high flux densities. More powerful permanent magnets and interesting developments in the nonmetallic magnetic materials can be anticipated also.

(Literature references are on the next page. See also 704-B for tabular data.)

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Battery of Presses for Punching Stator Laminations. Courtesy Westinghouse Electric Corp.

JEWELRY FIRM MAKES LOCK FOR BRIEFCASE

Above: Rexlock for Rexbilt Case, and its parts. Made by the jewelry firm of Augat Bros., Inc., Attleboro, Mass. Many parts of Revere brass.

Rexbilt Briefcase, made by Rexbilt Leather Goods Corp., 151 West 26th St., New York 1, N. Y.

THIS is the story of a briefcase. It has some unusual angles that will be entirely unsuspected by the men who happily tote the case. They would never guess it, but the interesting and quite new combination lock was made by Augat Bros., Inc., Attleboro, Mass. The Augats are manufacturing jewelers, long-time customers of Revere. If those who buy the Rexbilt briefcase think the lock is a jewel, they will be quite right.

Perhaps the Rexbilt Leather Goods Corporation, New York City, really did not have to go to a jewelry maker to have the new Rexlock made with the necessary precision. But you know how people are when they want to offer a really fine product. Fussy. That protects quality. Anyhow, Augat Bros. and Rexbilt are very happy, and so is Revere, for Revere brass is largely used in the lock wherever beauty, reliability and corrosion resistance are important. Some die castings and sheet steels are also used. This, then, is another good example of the wise choice of the proper materials to meet operating conditions, assuring prolonged service and enduring satisfaction to the user. Incidentally, not only is solid brass used liberally in the lock itself, but the handle posts are of the same enduring metal. Thus you have a combination of good metals, good leathers, a good lock idea, to make a quality briefcase . . . . Revere is always glad to collaborate with manufacturers seeking good metals, and welcomes the opportunity to study both new and old applications.

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Personals

Richard Summers, formerly a supervisor at Chase Brass & Copper Co., is now shop manager of Commercial Metal Treating Co., Inc., Bridgeport, Conn.

Upon completion of the requirements for M.S. degree from Virginia Polytechnic Institute, **Ronald F. Dickerson** has been employed as research engineer by Battelle Memorial Institute, Columbus, Ohio.

W. T. Sweeney, formerly director of research for Vernon-Benshoff Co., Pittsburgh, has been appointed research associate at the University of Michigan, working on research of dental materials in the School of Dentistry.

Vincent L. Goulet has opened an office for Universal-Cyclops Steel Corp. in Rock Island, Ill.

Russell C. Nelson, who received his B.S. from Lehigh University in October 1948, has enrolled at Colorado School of Mines to work for his M.S. in metallurgy.

R. L. Ashbrook is now with the Armour Research Foundation, Chicago, as assistant metallurgist.

Robert F. Hartmann, who received his B.S. from Missouri School of Mines and Metallurgy in June 1948, is now a student in the graduate school of the Chrysler Institute of Engineering, Chrysler Corp., Detroit.

Edwin E. Cornelius is now salvage engineer of Fairbanks, Morse & Co., Beloit, Wis.

E. C. Liker has organized Heat Treating Engineers, Inc., Milwaukee, a complete heat treatment plant. He was formerly associated with Claud S. Gordon Co., A. O. Smith Corp. and Allis-Chalmers Mfg. Co.

Charles A. Klein, formerly supervisor of the wire mill metallurgical laboratory at Halcomb works, Crucible Steel Co. of America, has become a partner in the Klein Co., Rochester, N. Y.

After graduating from Pennsylvania State College in June 1948, **George W. Cleveland** has been employed in the metallurgical department of the Bridgeport Brass Co., Bridgeport, Conn.

Jerard M. Pederson has accepted a position as an engineer in the aircraft gas turbine division of the General Electric Co., Lynn, Mass.

W. C. Royal is now representing Selas Corp. of America in Cleveland and northern Ohio. Mr. Royal was formerly sales engineer with the Pacific Gas Corp. in the midwest territory, and previous to this connection, he was associated with several gas utilities in Michigan and Indiana as industrial engineer.

Formerly metallurgist in the research and metallurgical laboratory of Simonds Saw & Steel Co., **Benjamin Falk** is now metallurgist with Arnold Engineering Co., Chicago.

J. N. Carter is now manager of the American Foundry and Machine Co., Salt Lake City, Utah.

Joseph Gurland has resigned his position of research engineer at Battelle Memorial Institute to complete graduate studies in metallurgy at Massachusetts Institute of Technology.

John R. Low, Jr., formerly professor and chief of the division of metallurgy, Pennsylvania State College, is now research associate at the Knolls atomic power laboratory of the General Electric Co. at Schenectady, N. Y.

Personals

Formerly metals specialist in the sales promotion department at Oakite Products, Inc., **Laurence W. Collins, Jr.,** ⊕ is now executive assistant to the vice-president of Callen Simon & Morton, Inc., New York City.

J. E. Boyle ⊕ has recently been made manager of the Western Fibre Co., Caseyville, Ill.

Carson B. Bartholomew ⊕, a recent graduate from Lehigh University, has joined Blue Ridge Pressure Castings, Inc., Lehighton, Pa., as a metallurgical engineer.

Ralph M. Heintz ⊕ has left active management of Jack & Heintz Precision Industries, Inc., to engage in research and development work for the company and the Government at the laboratory he will build at Los Gatos, Calif.

After graduating from the Colorado School of Mines with the degree of metallurgical engineer, **Edward D. Hyman** ⊕ has accepted a position as a metallurgist with the Federated Metals Div. of the American Smelting & Refining Co., San Francisco, Calif.

Robert W. Eck ⊕, formerly a metallurgical investigator with the Bethlehem Steel Co., is now vice-president of Eck Foundries, Inc., Manitowoc, Wis.

Donald Warren ⊕ is now a graduate student in the department of metallurgy at Lehigh University, Bethlehem, Pa.

After receiving his master's degree at the University of Illinois in June 1948, **Wells E. Ellis** ⊕ started to work for Timken Roller Bearing Co. as a research metallurgist.

Formerly with American Compressed Steel Co., **Jerry K. Weinberg** ⊕ is now metallurgical engineer for the Madison Smelting & Refining Co., Madison, Ind., of which he is also part owner.

After dissolving his partnership in the Alldredge & Simons Laboratories, **Sanford L. Simons** ⊕ has set himself up as an independent consulting engineer, offering services in research, design and development in the fields of metallurgy, mechanics and nuclear reactions.

Russell S. Solorow ⊕, mechanical engineer with the Schlumberger Well Surveying Co., is now in their new research laboratory in Ridgefield, Conn.

Personals

Joseph H. Faupel ⊕, formerly associated with the department of engineering mechanics at the Pennsylvania State College has joined the staff of the engineering department of the E. I. du Pont de Nemours and Co., Inc., Wilmington, Del., as a mechanical metallurgist.

Lo-ching Chang ⊕, formerly a staff member of the division of industrial cooperation of Massachusetts Institute of Technology, has joined Crucible Steel Co. of America as a metallurgist at the Atha works, Harrison, N. J.

Alfonso L. Baldi, Jr., ⊕ has joined General Chemical Div., Camden, N. J., as a design engineer.

Thomas C. Nelson, Jr., ⊕, a June graduate from the University of California, has become associated with the General Electric Co.'s Richland, Wash., plant.

Charles H. Avery ⊕, formerly with Carol-of-California Co., is now in the process engineering department of Northrop Aircraft Corp., Hawthorne, Calif.

Charles P. Gough ⊕ received his degree from Colorado School of Mines in May 1948, and thereupon accepted a position as metallurgist with American Smelting & Refining Co. at Selby, Calif.

George J. Miller ⊕ has left his position as student engineer at Geneva Steel Co. in Utah to take a position as junior metallurgist with the Homestake Mining Co., Lead, S. D.

Ralph G. Nevins, Jr., ⊕, previously an instructor and student at the University of Minnesota, has taken a position as instructor in the mechanical engineering department at Kansas State College, Manhattan, Kansas.

Francis M. Krill ⊕ has recently been employed as research metallographer with the newly organized laboratory of the Trentwood, Wash., plant of Permanente Metals.

Kenneth M. Gleszer ⊕ is now chief engineer of American Sintered Alloys, Inc.

Kenneth L. Tingley ⊕, who has been with Scovill Mfg. Co. since 1937, has been promoted from assistant manager of the mill production department to assistant superintendent of the casting shop.

Personals

D. W. McDowell, Jr., ⊕, formerly professor of metallurgy at Iowa State College, has joined the staff of the University of Buffalo, Buffalo, N. Y.

M. L. Johnson ⊕, formerly field engineer of the Stoody Co., covering the southeastern states, has been appointed assistant sales manager, and is now located at the Stoody plant in Whittier, Calif.

E. A. Baines ⊕ has accepted a position as sales engineer with Alloy Steel Products Co., Linden, N. J.

Mark M. Templeton ⊕ has been transferred by the Electro Metallurgical Co. from the Niagara works to the Sheffield, Ala., works, where he will be plant superintendent.

W. J. Childs ⊕, who graduated from Rensselaer Polytechnic Institute with a Ph.D. in June, has accepted an appointment as a staff member of the division of industrial cooperation at Massachusetts Institute of Technology, Cambridge, Mass.

Lawrence E. McIlvain ⊕ has left the McGill Mfg. Co. to open his own heat treating shop at Valparaiso, Ind.

Howard W. Schutz ⊕ has left the Josephtown, Pa., zinc smelter of the St. Joseph Lead Co. of Pa. to become a research metallurgist for the Eagle-Picher Co. at their central research laboratories in Joplin, Mo.

John T. Milek ⊕ has recently become associated with the Babcock & Wilcox Co.'s research and development department in Alliance, Ohio.

Warren K. Smith ⊕ has been transferred from the Foothill laboratory, Pasadena, Calif., to Michelson laboratory, Inyokern, Calif., where he will serve as metallurgist in the research department of the Naval Ordnance Test Station.

David F. Parker ⊕ is now at the research laboratory of General Electric Co. in Schenectady.

After graduating from Michigan College of Mining & Technology this past June, **George E. Brown** ⊕ has accepted a job as a metallurgist with the Carnegie-Illinois Steel Corp. at its Gary works.

Since his graduation from Carnegie Institute of Technology, **Michael Dripchak** ⊕ has been employed by the Scovill Mfg. Co., at Waterbury, Conn., as a student engineer.

Personals

H. W. Behme ⊕, who received his B.S. in chemistry from Rutgers University in 1948, has become a research engineer at Dorr Co., Westport, Conn.

Eutectic Welding Alloys Corp., New York City, announces the appointment of **Robert H. Groman** ⊕ to the board of regional sales supervisors, with responsibility for the west central area. Mr. Groman has most recently been assistant to the general sales manager.

Rockwell Mfg. Co. announces the appointment of **E. E. Hedene** ⊕ to chief engineer of all operations of the Nordstrom Valve Div. He was formerly the chief engineer of the Nordstrom Valve plant at Oakland, Calif.

G. C. Kuczynski ⊕, of the metallurgical research laboratories of Sylvania Electric Products, Inc., will deliver a series of lectures on the physics of metals at the National University of Bogota, Columbia.

E. H. Mebs ⊕, formerly division superintendent of foundries, Johnstown-Lorain works of Carnegie-Illinois Steel Corp., has been appointed to the newly created position of works manager, Machined Steel Casting Co., Alliance, Ohio.

Braeburn Alloy Steel Corp., Braeburn, Pa., announces the appointment of **Charles W. Schuck** ⊕ to the position of general superintendent of the plant in Braeburn. Mr. Schuck has served the company for the last eight years as metallurgist in charge of quality control.

W. W. Sieg ⊕, formerly executive vice-president of Titan Metal Mfg. Co., Bellefonte, Pa., has been elected president of the company.

Ray R. West ⊕, who has been with the industrial division of Minneapolis-Honeywell Regulator Co. in executive sales positions for the past 20 years, has been named manager of sales of products for industrial applications.

Electro Metallurgical Sales Corp. announces the transfer of **J. H. Spillane** ⊕ from the Chicago division to the general sales office in New York.

Key Co., East St. Louis, Ill., has recently promoted **Fred B. Riggan** ⊕, formerly chief metallurgist, to the position of foundry manager and general superintendent.

Regular inspection assures high welding quality levels . . .

One of the best ways to obtain consistently high quality in welding is to establish regular inspection with proved testing procedures. Radiography *is* a proved testing procedure, serving to control welding quality by providing objective information. This helps the operator maintain a high standard of workmanship...keeps plant and customer informed on the quality of every job.

Test non-destructively with x-rays to assure weld quality

Radiographs of all types of welds provide visible information on internal gas and slag pockets, lack of penetration, and other internal weld weaknesses. They also indicate to experienced welding technicians the best method to be used in preventing such defects. Radiographs are the best assurance an engineer can have that a welding job is well done.

For maximum radiographic visibility . . . use Kodak Industrial X-ray Films

They provide the high radiographic sensitivity—the combination of speed, contrast, and fine grain—required for the detail visibility you need in critical examination of welds.

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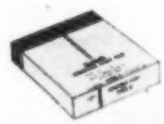
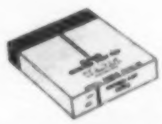
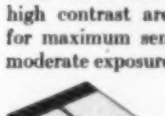


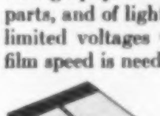
Kodak Industrial X-ray Film, Type A . . . for x-ray and gamma-ray work in sections where fine grain and high contrast are desirable for maximum sensitivity at moderate exposure times.



Kodak Industrial X-ray Film, Type K . . . designed for gamma-ray and x-ray radiography of heavy steel parts, and of lighter parts at limited voltages where high film speed is needed.



Kodak Industrial X-ray Film, Type M . . . first choice in critical inspection of light alloys, thin steel at moderate voltages, and heavy alloy parts with million-volt equipment.



Kodak Industrial X-ray Film, Type F . . . with calcium tungstate screens—primarily for radiography of heavy steel parts. For the fastest possible radiographic procedure.

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RADIOGRAPHY . . . another important function of photography

Kodak

Personals

William W. Rogers ● is now head of the mechanical technology department of the Long Island Agricultural & Technical Institute, at Farmingdale, L. I., N. Y.

Bruce C. Clark ● graduated from Colorado School of Mines in June 1948, and is now at the flotation mill of the U. S. Smelting, Refining and Mining Co., at Midvale, Utah.

John S. Culver ●, a June 1948 graduate from Illinois Institute of Technology, is now employed by the Douglas Aircraft Co. as a mechanical engineer.

Handy & Harman announce that **John W. Colgan** ●, sales manager of the company, has been elected a director.

Harris T. Gregg ●, manager of the Houston, Tex., branch of Metal Goods Corp., has recently been elected to a vice-presidency of the company.

Robert A. Stauffer ● has been appointed assistant director of research of National Research Corp., Cambridge, Mass., and **James H. Moore** ● has been promoted to director of the metals department succeeding Mr. Stauffer.

Michigan College of Mining and Technology announces the promotions of **R. W. Drier** ● to a professorship in theoretical and applied X-rays, and **R. J. Smith** ● to the rank of associate professor of metallurgy.

Federated Metals Division, American Smelting and Refining Co., announces that **A. M. Callis** ●, former sales manager of its Chicago territory, has been appointed to the newly created post of general sales manager. **J. W. Kelin**, former sales manager of the St. Louis territory, will be transferred to the Chicago territory and **Paul H. Jackson** ●, formerly at Seattle, Wash., will succeed Mr. Kelin at St. Louis.

Ralph A. Happe ●, formerly associated with the American Brass Co., has joined the staff of Battelle Institute, Columbus, Ohio, where he will be engaged in research in nonferrous metallurgy.

D. J. Blickwede ●, who has recently been awarded the degree of Sc.D. in metallurgy from Massachusetts Institute of Technology, is now in charge of high temperature alloy research at the Naval Research Laboratory, Washington, D. C.

Personals

Latrobe Electric Steel Co. announces the appointment of J. C. Bigham as district manager of sales in Philadelphia and R. C. Kohl as district manager of sales in Buffalo. Mr. Bigham was formerly a sales representative in the company's Detroit office and Mr. Kohl has been sales representative in the Buffalo area for several years. In addition, T. J. Bridgeman has been transferred by the company from the Chicago district to the Detroit district and L. C. Hansen has been changed from the cast alloy division to tool-steel sales in the Chicago area.

David M. Gans, formerly technical director of Quaker Chemical Products Corp., has been appointed director of research of the Arco Co., Cleveland.

W. H. Meyer, formerly with Copperweld Steel Co. and Ohio Industrial Steel Co., has been elected vice-president of Ohio-Penn Steel Co. of Pittsburgh. He will also be metallurgist of the newly formed company.

Courtney Combs, formerly an industrial engineer of Owensboro, Ky., has accepted a position as staff engineer with Associated Engineers, Inc., Fort Wayne, Ind.

Alexander Zekany, formerly with the National Tube Co., has been appointed sales metallurgist, American Cladmetals Co., Carnegie, Pa.

T. B. Focke has been named general manager of the airplane division, Columbus, Ohio, plant of the Curtiss-Wright Corp.

David K. Miller has been named Connecticut representative for Pratt & Inman steel warehouse of Worcester, Mass.

Samuel I. Hyman, formerly a junior engineer in the erection department of Babcock & Wilcox Co., is now with the distribution department of the Brooklyn Union Gas Co.

Joseph N. Peters has been appointed a sales engineer for Willey's Carbide Tool Co. in the Illinois area.

Bruce O. Leister, who was sales representative in St. Louis for Rustless Iron and Steel Corp. and Armco Steel Corp., is now vice-president and secretary of Metal Service Corp., Charlotte, N. C., distributors of steel and allied products in North and South Carolina.

Personals

Edward S. Smith is now a process engineer with the Carnegie-Illinois Steel Corp.'s Duquesne works, in the metallurgical department.

R. Lavin & Sons, Inc., announce that **W. M. Ball, Jr.,** has joined its technical staff as metallurgist and foundry consultant. For the past 27 years, Mr. Ball has been superintendent of the foundry of Magnus Brass Division of the National Lead Co.

Forrest E. Allen, formerly a member of the faculty of Iowa State College in the department of mechanical engineering and associate professor of metallurgy, has joined the development and research division of the International Nickel Co., Inc.

Dave Heckinger, formerly with Fansteel Metallurgical Corp., has accepted a position with Tools, Inc., as head of its Philadelphia office.

On completion of the General Electric scientific program, **George R. Hemmeter** has been assigned permanent placement in the Fort Wayne works of G.E. as a magnetic development engineer.

Formerly chief chemist for F. L. Jacobs Co., **Fred E. Seuffert** has been employed as chemist by Lyon, Inc., Detroit.

Leon V. Omelka, who received his degree of engineer in metallurgy at Stanford University in June 1948, is now employed by Permanente Metals at its Trentwood, Wash., research laboratory as a testing engineer in the mechanical testing department.

James H. Anderson, formerly instructor at the University of Minnesota, has been appointed assistant professor in the engineering department at San Jose State College, San Jose, Calif., where he will set up and supervise the metallurgy department.

J. Edwin Bride, formerly in metallurgical inspection department of materials review division, Wright Aeronautical Corp., Lockland, Ohio, has joined Battelle Memorial Institute, Columbus, Ohio, to conduct research in electrochemistry.

After graduating from Colorado School of Mines, **Curtis L. Horn** has accepted a position as metallurgist in the metallurgical engineering department of Reed Roller Bit Co., Houston, Tex.

Personals

Formerly with Battelle Memorial Institute in the welding research department, **Howard B. Cary** is now welding engineer for Marion Power Shovel Co., Marion, Ohio.

After completing work for his degree in metallurgical engineering at the University of Minnesota, **Robert G. P. Anderson** has joined the college graduate training class of the Caterpillar Tractor Co.

After graduation from the University of Minnesota in June 1948, **Herbert F. Clyne** has been employed at the Zenith furnace plant of Interlake Iron Corp., Duluth, Minn., studying blast furnace operations.

John L. Everhart is now a metallurgist in the research division, American Smelting & Refining Co., Perth Amboy, N. J.

S. S. Harrington is now works manager of the Kane & Roach Co., Syracuse, N. Y., manufacturers of cold roll forming and bending machinery.

Edmund C. Burke has left the Cleveland division of the research laboratories of the Aluminum Co. of America to take graduate work in metallurgy at Yale University.

After 11 years with the Wheelco Instruments Co., **Clarke H. Joy** has formed the Clarke H. Joy Co. which will distribute Wheelco products and those of Precision Thermometer and Instrument Co. in the Cleveland area.

After graduation from Carnegie Institute of Technology, **Edmund C. Franz** has accepted a position as metallurgist in the research division of the Aluminum Co. of America at Cleveland.

Arthur P. Siewert has been transferred from the Danville plant of the Central Foundry Div. of General Motors Corp. to the division's Lockport plant, with the promotion to plant metallurgist.

Robert D. Kesler, who graduated from Colorado School of Mines this year, has accepted a position with Battelle Memorial Institute, Columbus, Ohio, as engineer doing mineral dressing research.

Thomas A. Read, who was previously principal physicist in the Oak Ridge National Laboratory, has been appointed associate professor of metallurgy at Columbia University.

Personals

S. L. Channon, formerly of Australia, has been awarded a research assistantship at the University of Illinois, where he will work toward his Ph.D. He has recently graduated with an M.S. degree from University of Utah.

K. G. Carpenter is sales representative for Permanente Products Co., Philadelphia, Pa.

C. R. Eppinger has been transferred by Horace T. Potts Co., Philadelphia, from manager of telephone sales to salesman in the York, Pa., area.

After graduating from the University of Cincinnati, **Robert M. Van Hoy** has accepted a position with David Bradley Mfg. Works, Bradley, Ill., as methods engineer and materials handling engineer.

George H. Fromer has been appointed quality control manager of the drop forge division of Willys Overland Motors, Inc., Toledo, Ohio.

After receiving his B.S. in metallurgical engineering at the University of Illinois in June 1948, **John W. Pugh** has joined the General Electric Co. as a member of its scientific program.

Ray E. Huffaker has been employed in the metallurgical department of the Ladish Co., Cudahy, Wis.

Donald A. Potter, formerly with Universal Castings Corp. as chief engineer, is now a project engineer in charge of aircraft heater engineering at Stewart Warner Corp., Indianapolis, Ind.

C. W. Jordan, Jr., was graduated from Carnegie Institute of Technology in June 1948 and is now employed as control metallurgist for Wisconsin Steel Div. of International Harvester Co., South Chicago, Ill.

Following graduation from the school of mines of the University of Pittsburgh, **Robert J. Hamilton** has accepted a post as instructor at Geneva College, Beaver Falls, Pa.

Marvin L. Buehler is now a laboratory foreman in the tin mill at Columbia Steel Co., Pittsburg, Calif. He graduated from Colorado School of Mines in May 1948.

The Aluminum Co. of America has transferred **E. M. Strauss, Jr.,** from the Baltimore sales office to the Fairfield, Conn., sales office.

Personals

K. E. Niewoehner, formerly of Missouri School of Mines and Metallurgy, is now enrolled in the "Loop" training course of Bethlehem Steel Co., at the Johnstown, Pa., plant.

Donald A. Nelson has recently accepted a position as a research scientist at the National Advisory Committee for Aeronautics' flight propulsion research laboratory at the Cleveland Airport.

Frank A. Rough has been employed in the physical metallurgy section of Battelle Memorial Institute, Columbus, Ohio.

Dan R. Gannon, Jr., formerly manager of distributor sales of the La Salle Steel Co., Chicago, is now manager of the steel department of Vinson Supply Co., Dallas, Tex.

James Bard has enrolled in the training program of Bethlehem Steel Co. after receiving his B.S. degree in metallurgy at Pennsylvania State College.

Herman Mansfield is now a research metallurgist at Sylvania Electric Products, Inc.'s, Bayside, L. I., laboratories.

D. C. Einfurer, after receiving his M.S. in metallurgy from Stevens Institute of Technology, has become chief metallurgist of Walter Kidde & Co., Belleville, N. J.

Paul B. Parker has recently accepted a position with the specifications branch of the Corps of Engineers at Rock Island, Ill.

Announcement is made of the retirement from active duty of G. E. F. **Lundell**, chief of the chemistry division of the National Bureau of Standards. He will be succeeded by **Edward Wichers**, formerly assistant chief and head of the section on reagents and platinum metals. **William Blum**, head of the electrodeposition section, was named assistant chief of the division.

Harry T. Loynd has been appointed manufacturing representative for Allegheny Ludlum Steel Corp. with headquarters at Brackenridge, Pa.

Announcement is made by Lebanon Steel Foundry, Lebanon, Pa., that **Edward H. Platz** has been appointed manager of alloy steel sales. Mr. Platz has been with Lebanon Foundry since 1939, and previously was with Duriron Co.

Personals

Formerly employed by the Cincinnati Milling Machine Co. and the Alexander Engineering Co., **H. P. Baecker** ⊜ is now planning engineer of the Rohr Aircraft Corp., Chula Vista, Calif.

Following graduation from the University of Illinois with a B.S. in metallurgy, **Earl A. Hasemeyer** ⊜ is now employed at Western Cartridge Co., East Alton, Ill., in its training program.

Richard S. Crowell ⊜ is now employed by the Carnegie-Illinois Steel Corp.'s Clairton, Pa., works, as a process engineer for the metallurgy department.

Stephen D. Smoke ⊜, formerly with the National Tube Co. and the Bethlehem Steel Co., has been appointed an associate editor for *The Iron Age*.

D. A. Craig ⊜ has been transferred by Phillips Petroleum Co. from the laboratory in Bartlesville, Okla., to the Panhandle area where he will be engaged in metallurgical test and inspection work.

R. M. Garrison ⊜ is now chief engineer for the Verson Allsteel Press Co. of Chicago.

Frank Bruns ⊜ is now employed by the Standard Oil Co. of Indiana in the Whiting refinery as an inspection engineer.

Norman G. Eley ⊜ has been appointed to the graduate school at the Chrysler Institute of Engineering on his graduation from the University of Toronto.

Wm. Hendrickson ⊜ has been transferred by Carbide & Carbon Chemical Corp. from field inspector with headquarters in New York City to the Charleston, W. Va., plant.

After completing studies at Michigan College of Mining and Technology under a scholarship from the General Electric Educational Fund, **Marshall W. Stevens** ⊜ has been re-engaged as foundry metallurgist in the Bridgeport works laboratory of General Electric.

Frank J. De Rewal ⊜, formerly a research engineer at Foote Mineral Co. and Battelle Memorial Institute, is now owner of De Rewal International Rare Metals Co., Philadelphia, producers of zirconium, titanium, hafnium, cesium and rubidium.

Personals

Chester F. Gatczak ⊜, a recent graduate from Purdue University, is now a research metallurgist at Timken Roller Bearing Co.'s research department.

F. G. Scarborough ⊜ is now engineering officer of the U.S.S. Dayton, operating in the Atlantic Ocean.

After 13 years with General Electric X-Ray Corp., **H. G. Thompson** ⊜ is now quality engineer with the Master Electric Co., Dayton, Ohio.

Atomic Engines for Aircraft*

ATOMIC energy as a source of power for aircraft promises to achieve a result unobtainable with standard fuels — airplanes combining extremely high speed and almost unlimited range. Our present supersonic airplanes run out of fuel in a matter of a few minutes. With atomic energy, they could keep on going, for the fuel supply would remain nearly constant.

Several basic types of power plants can be adapted to atomic power. One is a closed cycle where some medium, like mercury, may be heated and give its energy to a turbine which drives a propeller. The required propeller and air-cooled condenser will limit the airplane speed, and is not as attractive as other possibilities.

Next is the turbo-jet, where the reactor heats compressed air and the energy of the expansion (less that amount required to compress the air) provides thrust for the airplane. This seems well suited to high-speed airplanes.

The simpler ram-jet (like the turbo-jet, except that the air is compressed by forward speed of the plane) requires a high speed to function at all and becomes really effective at extreme speeds high in the supersonic region. The air temperatures required by the ram-jet are considerably higher than needed by the turbo-jet. At the same time, it is very sensitive to pressure variations, external or internal. Good heat transfer conditions must always be paid for by appreciable pressure drops. The ram-jet is not a simple problem.

(Continued on page 746)

*Abstracted from *The Pegasus*, August 1948, p. 1.

Atomic Aircraft

(Continued from page 744)

Finally, in the application of nuclear energy as a rocket-type power plant, a propellant gas is taken from storage tanks and heated by the reactor; it exhausts at high velocity and provides the necessary thrust. It is not dependent on atmospheric air and can operate outside the earth's atmosphere. The maximum impulse per pound of fuel used per second results from a combination of the highest possible temperature and the lowest possible molecular weight of the fuel. There will be no need for combustion, and a very light propellant like hydrogen can be used. (The specific impulse of pure hydrogen at the same temperature is three times that of water vapor.)

With fuel like uranium, with a heating value of 40 *billion* Btu. per lb., fuel consumption is vanishingly small. High performance, however, calls for high operating temperatures, and this is aggravated by the heat-transfer problem. Hot exhaust gases require very much hotter internal surfaces of the reactor.

On the other hand, there are no moving parts in the reactor and its elements are not subjected to high dynamic stresses. It can be said broadly that the temperatures necessary are not unreasonable from the metallurgical standpoint. They do nevertheless engender such difficult problems as the protection of the uranium from reaction with the working fluid (the "canning" problem) and the protection of the equipment and personnel from radioactive fission products. This brings up the weight of necessary shielding.

The "engine" component of a nuclear power plant [turbine-driven accessories] may be expected to weigh approximately the same as a conventional power plant of the same horsepower or thrust rating. The weight of reactor and shielding must therefore be lighter than the weight of the fuel and fuel tanks in a chemically fueled aircraft. In present-day long-range airplanes, this is sometimes over 50 tons. It is obvious that the atomic-powered airplane is in an entirely different category from the atomic-powered automobile. (The range of an atomic-powered airplane is practically unlimited and is not a design variable.)

Making the reactor small is an obvious way of reducing weight of

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Atomic Aircraft

(Continued from page 746)

shielding. However, this will require the release of energy at a high rate in a small volume. Although a nuclear reactor can potentially generate heat at a practically unlimited rate, this heat must be conducted from the interior of the fuel rod to its surface and then transferred to the working fluid; this means high temperature differentials, high pressure drops, large internal surface areas and all other difficulties associated with high-power densities. Furthermore, the smaller a reactor is, the larger the ratio of its surface area to its volume and the easier it is for neutrons to escape without causing new fissions. A smaller reactor may therefore require a much larger investment of uranium in order to sustain the chain reaction.

Shielding a material which is known to be good for stopping gamma rays may not be the best when gamma rays and neutrons are considered together, and a material which is good for the innermost part of the shield may not be best for the outer layers. Since we are dealing with a relatively thick shield surrounding a relatively small reactor, the apparent paradox holds true that, for a given mass thickness, the greater the density of the shielding material the lighter the shield! It should be realized in this connection that the radiation intensities must be reduced by factors of many billions before they are safe for humans. Also, the effect of intense radiation on the properties of the materials must be considered, and electrical resistance, elasticity and heat conductivity of graphite (for example) all change with exposure to intense neutron radiation.

The airplane must be designed for very high speeds to take advantage of the special characteristics of atomic power. It certainly will be a large airplane. If it has a turbo-jet power plant, it will have to be designed for a landing weight which is equal to take-off weight, since practically no fuel will be used up in flight. Because of radiation, the crew locations should be placed as far away from the power plant as possible.

These are some of the problems associated with the development of a nuclear aircraft power plant. They are not insurmountable, but by no means easy.

Seymour

PHOSPHOR BRONZE ROD

MANY STANDARD SIZES NOW IN *STOCK!*

Prompt deliveries of 1/8" to 2" diameter rod are now being made in both outstanding Seymour Phosphor Bronze mixtures listed below.

To offer you this improved service, we have built up a complete range of finished and ready-to-finish bar sizes. This enables us to supply your immediate, emergency requirements from stock, or make shipment of larger, mill run quantities within two or three weeks.

ROD

SPECIAL FREE TURNING PHOSPHOR BRONZE
88% COPPER 4% TIN 4% LEAD 4% ZINC

Tensile strength PSI	60,000
Elongation % in 2"	20
Elec. Cond. % I.A.C.S. at 20°C	12%
Machinability (Free cutting Brass equals 100)	100%

For all types of screw machine products. Also gears, bearings, pinions, etc. Used where a combination of excellent machinability, toughness and corrosion resistance is a "must."

ROD

GRADE B PHOSPHOR BRONZE
94% COPPER 5% TIN 1% LEAD

Tensile strength PSI	60,000
Elongation % in 2"	20
Elec. Cond. % I.A.C.S. at 20°C	16
Machinability (Free cutting Brass equals 100)	50%

For products demanding qualities of non-leaded Phosphor Bronze yet which must be cut, threaded or milled. Used on high speed automatic cutters.

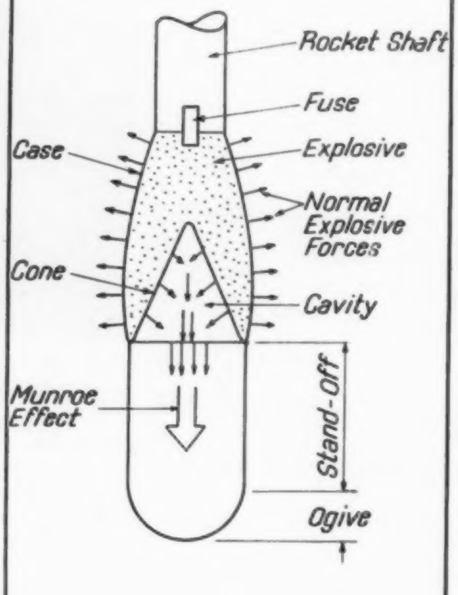
SEYMOUR

THE SEYMOUR MANUFACTURING COMPANY, SEYMOUR, CONN.

Bazooka Shells*

BELIEVE it or not, *Scribner's Magazine* in 1888 described the business end of the bazooka. Whether the article was placed in the wrong journal, or whether the facts recounted had only slight interest, Prof. Charles E. Munroe's discovery of the intensified effect of an explosion at the mouth of a hollowed charge had to be rediscovered in Germany in 1911 and exhumed by U. S. Army ballistics experts during World War II.

The "Munroe effect" is the basis not only of the bazooka's power (which neatly drills a hole through heavy armor and pours through it a torrent of flame and melted metal) but also of "placed charges", called "bee-hives" by the British, which blast a hole through thick reinforced concrete with an explosive charge carried and attached by one man.



The shape of the hollowed charge is shown in the adjoining sketch of a sectioned bazooka rocket war head. The explosive forces on the periphery of the cavity liner, which presumably act with equal intensity in all directions, will have a resultant force normal to the surface of the liner, working progressively down from its apex. If the cavity is symmetrical, these forces meet at the axis, are additive, and thus concentrate the kinetic energy that would other-

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*Abstracted from "Secrets of the Shaped Charge", by George B. Clark, *Ordnance*, July-August, 1948, p. 49.

Bazooka Shells

(Continued from page 750)

wise be spread over a considerable area of the sphere of explosive effect.

Among the factors that affect the performance are stand-off (distance from target), type of explosive, height of explosive, kind of metal in liner, apex angle of liner, thickness of liner, confinement of charge, and the effect of the detonation wave in a cast-iron liner. Of these factors, none can be denoted as more important than any other.

All the liners used in the tests were made as unmachined castings of lead, aluminum, aluminum alloy, and zinc. Liners made of metals of higher melting point were annealed.

There is no apparent relationship between the melting points of the metal and its performance in producing Munroe jets. Brittleness, hardness, cohesiveness, and other properties appear to affect performance more than melting point. Lead, which is the softest of the metals tested and has the lowest melting point, produced lower penetration values than the other metals and made a wider crater.

Aluminum, which has a higher melting point than zinc, gave lower penetration values than the zinc. This would lead to a possible conclusion that brittleness is one of the desirable characteristics of a metal for shaped-charge cavity liners. An aluminum alloy, with much higher tensile strength than any of the other metals, gave the best performance of any of them.

Thus it appears that metals having a fortuitous combination of hardness, brittleness, cohesiveness, and ability to flow uniformly when subjected to high pressures give the best results in producing Munroe jets.

Thickness of liner-penetration of Munroe jet (as measured on granite) depends on a complex relationship between apex angle of cone and thickness of liner. Optimum wall thickness for a 60° cone, 3-in. mouth, made of cast iron, is about $\frac{3}{16}$ in. Slightly tapered walls ($\frac{1}{8}$ in. thinner near apex) are more effective.

Prior to experimenting with cast molybdenum steel cases, it was thought that a thick case would act like a breechblock for the charge — the Munroe jet being the projectile. Actually the improvement with 3-in. walls was not so great as expected.

In these tests, the total effect of confinement on the performance of shaped charges was to increase both depth and diameter of the hole produced. The mechanics of this increased effect are probably threefold: *(a)* The action of rebounding gas molecules from the inside surface of the case has an effect on more complete and perfect detonation of the explosive, ensuring propagation of the high velocity of detonation; *(b)* much more of the force of the explosion itself is directed toward the point of least resistance, the cavity end of the charge; and thus *(c)* more of the explosive force is directed against the cavity liner itself to give a stronger jet.

Dynamic pressures in the burning zone of a high explosive are so high that they will cause brittle cast iron to flow easily and will re-form it without apparent failure.

There is probably little known about the actual processes of deformation of metals under these tremendous pressures. Both interatomic and intercrystalline forces are involved, but deformation happens so rapidly that the readjustments in the metal cannot be studied by methods now available. ●